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THE

PHYSICAL REVIEW.

THE MEASUREMENT OF THE RESONANCE, RADIATION, AND IONIZATION POTENTIALS OF SEVERAL GASES AND VAPORS.

By Paul Edward Boucher.

Synopsis.

Minimum Resonance, Radiation and Ionization Potentials for Various Gases.—A special vacuum tube was used which embodied a modification of K. T. Compton's variable-area electrode by being so designed that either a gauze or a plate electrode could be slid into the position of the fourth electrode. The resonance potentials were obtained from the difference in voltage between successive peaks of the resonance curves; the ionization potentials from Lenard current-voltage curves corrected as to zero by the resonance curves; the relative importance of radiation and ionization at various voltages from the ratio of the Lenard currents obtained with the plate, to the corresponding currents obtained with the gauze electrode having only one fourth the area. The critical potentials in volts, accurate to about 0.1 volt except for toluene, are as follows:

Gas.	Resonance Potential.	Radiation Predominant.	Ionization Potential.
Hydrogen	10.1	10.1 to 13.6	13.6; 15.6
Nitrogen	8.4	8.4 to 15.8	15.8
Oxygen	8.0	None detected	14.0
Ether ($C_4H_{10}O$)	6.6	8.1 to 10.1	13.6
Benzene (C_6H_6)	6.0	None detected	9.6
Toluene (C_7H_8)	6.2 ± 0.2	" "	8.5 ± 0.5
Xylene (C_8H_{10})	6.5	" "	10.0
Chloroform ($CHCl_3$)	6.5	" "	11.5

The results for the resonance potentials for H_2, N_2 and O_2 agree with those obtained by Foote and Mohler, but the values for the corresponding ionization potentials are about 1 volt higher than theirs. The fact that no radiation was detected in the case of O_2 and of all the vapors except ether is rather remarkable; but it may be due to the method used.

A. Introduction.

A CONSIDERABLE amount of research has been carried out on the radiation and ionization potentials of various gases and vapors. The problem has been attacked in several ways but the results are not

in such good agreement as could be desired. The Bohr theory has been applied only to the hydrogen and helium atoms with much success. As time goes on we may expect extensions of this or other theories to other elements and even to compounds. The development of a satisfactory theory rests upon the accuracy with which the radiation, resonance, and ionization potentials can be determined. In this paper the writer describes methods and gives the results in which the critical potentials of several simple gases and compounds have been measured.

Some preliminary work was carried out, in which several ionization tubes of various designs were constructed and tested. Only the final form of the apparatus will be described here.

B. APPARATUS.

The problem of distinguishing between radiation and ionization is one of some difficulty. Davis and Goucher[1] have used a modification of the Lenard method in which they reversed the direction of the retarding field between two of the electrodes. A photoelectric effect due to radiation would give a current the direction of which would depend only on the direction of the retarding field, while a positive ion current due to ionization would be obtained with the retarding field in one particular direction. Other observers using the same method have not obtained consistent results.

K. T. Compton in the Philosophical Magazine for November, 1920, describes a three-electrode tube, having a variable area receiving electrode. This electrode consists of a cylinder closed at one end with a piece of foil and at the other with a piece of fine gauze. Either end could be turned towards the cathode, and thus the area exposed to radiation could be changed and a consequent variation in photoelectric current proportional to the area exposed might be expected. If the effect were one of ionization then a variation in the electrode area would not change the current.

The principle of a variable area electrode was employed, though the design was entirely different from that of Compton's. Fig. 1 will give an idea as to its construction. It was a four-electrode tube, though most of the time it was used as a three-electrode tube, two of the electrodes being connected together. The filament *A*, the platinum cylinder *B*, and the gauze *C* were mounted on the glass stopper *T*. This large glass stopper was fitted to the main part of the tube by a very fine ground glass joint. A small amount of grease was placed around the lower part of the joint, but several days would elapse before the grease could be

[1] PHYSICAL REVIEW, Vol. 10, No. 2, August, 1917, p. 101.

noticed working its way towards the vacuum. During the latter part of the work, the grease was entirely removed and the joint was sealed in with a mixture of beeswax and rosin. The ground joint was 8 cms. from the cathode, so that it did not become appreciably warm. Because of the large size of the opening, the entire assembly of the electrodes, *A*, *B*, and *C*, could be removed at will for alteration or repair.

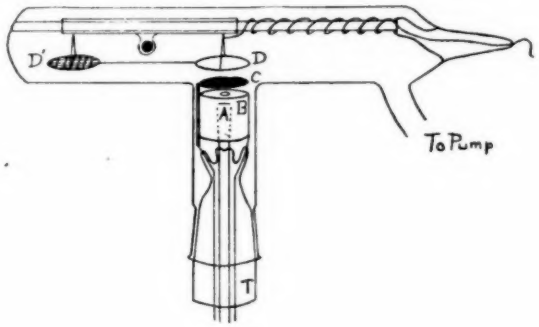

Fig. 1.

The cathode *A* was a piece of platinum foil 1 cm. in length, cut narrow at the center, so that the central portion became much hotter than the ends, thus furnishing the larger portion of the supply of electrons and hence approximating to an equipotential source. It was coated with lime and baryta by giving it several coats of sealing wax and heating it at a high temperature in air before being placed in the tube.

The platinum cylinder was 2 cms. long, 2.5 cms. in diameter, and closed at one end except for a circular opening 0.5 cm. in diameter. The cylinder was thus slipped over the cathode so that the small hole was about 3 mms. directly above the cathode. A fine gauze placed over the small hole was found to improve the operation of the tube.

A small glass stem furnished both the support and the means of insulation for the fine gauze electrode *C*. This electrode was placed 6 mms. distant from the cylinder.

The innovation, the electrode of variable area *DD'*, consisted of a platinum foil disk of 3 cms. diameter, and a very coarse gauze disk of the same diameter. These were connected by a stiff wire 5 cms. long, and the whole was suspended from a glass sleeve. A glass rod fixed permanently in the tube, formed the track upon which the glass sleeve could be moved back and forth. A small piece of soft iron, enclosed in glass, was sealed to the movable electrode at *E*. Thus by means of an electromagnet outside the tube, the electrode could be moved so that either the solid disk or the coarse gauze was directly above the electrode *C*. It was

thought by placing these parts of the electrode 5 cms. apart, that while one disk was directly above C, the other would be too far away to receive any appreciable effect either due to radiation or ionization. The meshes of the coarse gauze were about 6 mms. square. The total effective area of one side that would be exposed to radiation was 7 square cms. for the solid disc, and 1.87 square cms. for the gauze. Thus the ratio of their effective areas was about 3.78. So that if the current received were entirely due to radiation incident on the electrode, it would be almost 4 times larger for the solid disc than for the gauze. A fine coil of platinum wire formed the flexible lead to the outside of the tube. All parts were made of platinum, so that before being connected to the pump, the entire tube was washed several times in nitric acid, rinsed in ammonia and distilled water and then dried in an electric oven.

C. Methods Employed.

Three methods of operation were employed with tube No. 4. Figure 2 shows the connections which were essentially the same for the three methods. The cathode A was heated by four 7-volt Edison storage batteries. This number was found to be advisable in order to obtain steady electron currents, because from 4 to 6 amperes of current were required to raise the cathode to the desired temperature. This source of current was found to be fairly constant. During most of the work, a piece of fine gauze was stretched across the small hole in the cylinder B. In the preliminary tryout of the tube, the cylinder was removed, but the results were very unsatisfactory and it was replaced. C is the fine gauze and DD' is the movable electrode by which the area exposed to radiation could be varied. B and C were connected together most of the time.

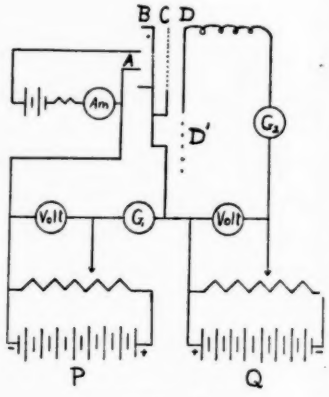

Fig. 2.

The methods employed are called the Lenard, the ratio, and the resonance methods. The Lenard and the ratio methods were used simultaneously, that is, data by which ratio curves were plotted, were obtained from the Lenard readings. Battery P furnished the accelerating potential V_a, which was applied between the cathode and BC. For the Lenard method battery Q furnished the retarding potential V_r, which was applied between the variable area electrode DD' and BC. This potential was always larger than the highest value of the accelerating

potential used, usually about 30 volts. Thus BC was charged plus with respect to A, and electrons from the cathode would move to BC. Some would pass through the gauze covered opening into the space BC, where they would travel at a constant velocity, since the electric field in BC was zero. Those electrons which did not collide with atoms or molecules in BC and possessing sufficient velocity would pass through the fine gauze C into the space CD. Here however the large retarding potential V_r would prevent any electrons reaching D. Let us suppose that the electrons have attained a velocity V_a sufficient for them to cause the atoms they collide with to give off radiation. Then some of this radiation will fall on the movable electrode DD', and due to what is called the photoelectric effect, electrons will be emitted from DD' and due to V_r will pass from DD' to BC, and we will have a current measured by the high sensitivity galvanometer G_2. This special Leeds and Northrup high sensitivity galvanometer had a sensitivity of 5×10^{-11} amperes per mm. deflection. Now the value of the radiation current will depend on the area of the electrode exposed to radiation. Since the ratio of the area of the solid disc to the coarse gauze is about 3.8 we should expect the current to the disc to be almost four times that to the coarse gauze, provided the effect is purely one of radiation. On the other hand if the velocity of the electrons is sufficient to produce ionization by collision, then the positive ions formed will go to the electrode DD', and we will have a current indication on the galvanometer in the same direction as for radiation effects. However if we vary the area of the electrode DD', there will be no change in the value of the current since the ionization does not depend on the area of the electrode exposed. Thus we have a means for distinguishing between radiation and ionization. The procedure in obtaining the necessary data for the ratio test was to take first a reading of the Lenard current with the disc end of the movable electrode above C, then by means of an electromagnet move the gauze end above C, and again read the current value, the accelerating and retarding potentials meanwhile remaining constant. This procedure was continued for each value of accelerating potential applied. Dividing the current value to the disc by the current value to the coarse gauze we obtain the ratios of the currents for the various V_a's applied. And we can conclude, at least with our present knowledge of the subject of photoelectric and ionization effects, that if the ratio approaches 4 in value, the effect is entirely due to radiation; if it becomes 1, then it is due to ionization, while if the ratio has some intermediate value between 1 and 4 both ionization and radiation are present.

The only change necessary to obtain resonance currents is to make the

retarding potential V_r small, say 1 to 5 volts, instead of 30 volts as in the Lenard method. The collisions between electrons and the atoms of some gases appear to be elastic up to a certain velocity. Beyond this point, the collisions become inelastic, that is the colliding electrons give up their energy to the atoms or molecules, which in turn is used to remove one of the atom's electrons from its stable position to an unstable one, and thus radiation of frequency n is produced when the electron falls back into its stable position. Thus when inelastic collisions take place the colliding electrons lose their velocity. If the retarding potential is small and the accelerating potential is increased from zero, the electrons will acquire a velocity which will enable them to reach the electrode DD' against the retarding potential. When inelastic collisions take place, however, some of the electrons lose their velocity and these are unable to reach DD' against the retarding potential and a consequent decrease in electron current takes place. But as the increase in the accelerating potential is continued these electrons again increase in velocity and the electron current begins to increase in value once more. This increase continues, as the potential goes up, until the electrons have acquired a velocity such that inelastic collisions again take place, and we have a second decrease in current. As many as four resonance points in a current voltage curve have been obtained.

It is found that the gas pressure at which resonance curves may be obtained is limited in range. The best resonance curves are obtained between gas pressures of about 0.1 mm. to 2 or 3 mms. No doubt the distance between the electrodes is a factor in obtaining resonance curves, though just how it would affect the critical pressure is not known. The resonance potential may thus be accurately found by taking the difference in accelerating potential between two consecutive resonance points. It should be remembered that an atom or molecule does not necessarily give off radiation at its resonance potential.

The initial correction due to several factors, the initial velocity of the electrons, the contact difference of potential between the cathode and the receiving electrodes, the potential drop along the filament, may be obtained from the resonance curves. In most cases the potential at which the first resonance peak is obtained, is not equal to the difference between two resonance peaks. For any gas the difference between two resonance peaks is found to be always the same no matter what conditions prevailed. The writer found considerable variation in the applied potential difference at which the first resonance peak occurs. Mohler and Foote[1] have published some work on the "Ionization and Resonance

[1] Scientific Papers of the Bureau of Standards, No. 400.

Potentials of some Non-metallic Elements," in which they obtained the first resonance peaks with applied accelerating potentials of smaller value than the resonance potentials as read from the difference of two succeeding resonance peaks. In practically all the work reported in this paper, the initial applied accelerating potentials for the first resonance peaks were either equal to or greater than the resonance potentials. The explanation of this is not clear. It may perhaps be due to contact difference of potential in the cathode itself. We need not know the magnitude of the corrections in order to obtain the proper correction for the Lenard curves. This correction was obtained by taking the difference between the resonance potential and the applied potential at which the first resonance peak begins, and adding or subtracting it as the case may be to the ionization and radiation potentials obtained by the Lenard method.

The general procedure for obtaining the radiation and ionization potentials of any gas was as follows: The tube was first heated to about 300° C. in an electric heater, and the cathode was also heated to a high temperature to help free the electrodes and glass from occluded gas. Liquid air was placed on the trap and the pump was started. This treatment was continued for several hours with a new tube, and was always repeated for an hour or more before each day's work was begun. After such treatment the Gaede pump would give vacuums of the order of 10^{-4} mms. The gas to be tested was then admitted to the desired pressure, and by means of a Geissler tube and an Adam Hilger direct-reading spectroscope, the purity of the gas was tested. If not satisfactory it was pumped out and refilled. Readings were never recorded until the currents became constant in value. After a set of readings was taken, several potentials were rechecked and if the current values varied more than a few mms. deflection on the galvanometer the data were rejected. For any gas pressure data for the resonance curves were first taken and then that for the Lenard and ratio curves.

For admitting the vapors, a bulb connected to a three-way stopcock was sealed on close to the electrode tube. A little of the liquid was poured into the bulb, then it was frozen by liquid air, and all the gas was pumped out above the frozen liquid. The stopcock was then closed, the liquid air removed, and the pure vapor could be admitted as desired. Some difficulty was experienced in admitting the proper amount of vapor. Due to the sudden expansion of the vapor on entering the vacuum, some would condense on the walls of the tube, and considerable time would be required to obtain the desired pressure. It was found however that by first getting a large electron current in vacuum and then just admitting

enough vapor to cause this current to decrease, that the desired pressures could be obtained much more quickly.

D. EXPERIMENTAL RESULTS.

The experimental results obtained in measuring the radiation and ionization potentials of several gases and vapors will now be described in the order performed.

1. *Hydrogen.*

Hydrogen for this test was prepared by the action of caustic potash on aluminum. It was found very convenient to store the gas in a tank under water pressure, so that if any leakage should take place, it would be only loss of hydrogen. A calcium chloride tube was inserted between the storage tank and the ionization apparatus. This tube could be exhausted before admitting hydrogen. The apparatus was always washed out several times with the gas in question before adjusting the

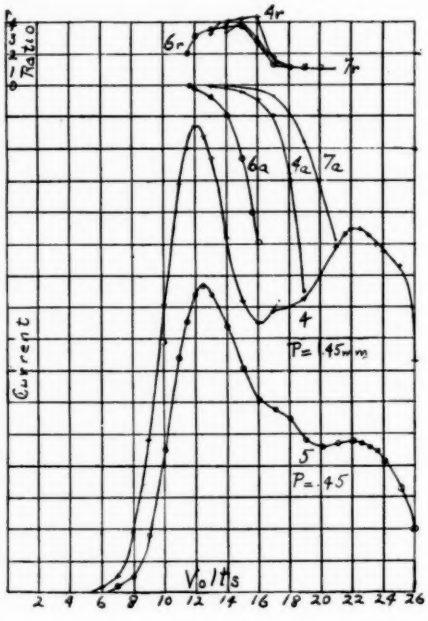

Fig. 3.

pressure for a test. Liquid air was always kept on the trap during these tests. The purity of the gas was tested by examining its spectrum.

Some characteristic curves obtained with hydrogen gas are shown in Fig. 3. Curves 4 and 5 are resonance curves, obtained at the same pressure, but at different filament temperatures. Curves 4*a*, 6*a*, and 7*a*

are Lenard curves obtained at the same pressure but at different filament temperatures. These are the current values measured to the disc of the movable electrode while obtaining the two sets of data from which the corresponding ratio curves were plotted.

The resonance curves give these results:

Curve.	1st Res. Pt.	2d Res. Pt.	Difference.	Correction.
4.....	11.5	21.6	10.1	10.1 − 11.5 = − 1.4
5.....	12.0	22.0	10.0	10.0 − 12.0 = − 2.0

Curve 4 gives a break at 17 volts, and adding the correction (− 1.4 volts) to this gives, 17.0 − 1.4 = 15.6 volts, which is the ionization potential as determined from the resonance curves. Lenard curves 4*a* and 7*a* both have sharp increases in current at 17.0 volts. Referring to the ratio curves this is evidently the potential where strong ionization predominates. Applying the correction we have 17.0 − 1.4 = 15.6 volts for the ionization potential of hydrogen. Curve 6*a* gives a resonance potential at 11.6 − 1.4 = 10.2 volts. Thus it will be seen that the resonance and ionization potentials obtained by the three methods check very well indeed. The break in the resonance curves due to ionization at 15.6 volts was not obtained in all curves. The ionization at this potential evidently prevents the second resonance peak from being as high and sharp as the first. This can be readily explained by the fact that when ionization sets in both plus and minus ions are formed. Remembering that the resonance currents consist simply of electrons possessing sufficient velocity to go against the small retarding potential applied between the movable electrode and *BC*, it will be readily seen that any sudden introduction of positive ions would tend to diminish the electron current, for the positive ions would be attracted by the retarding field to the movable electrode. If the effect were strong enough we might get a complete reversal of current. This has been obtained with some of the vapors worked with and will be referred to again.

The ratio curves deserve further consideration. Radiation and some ionization appear to exist at 10.2 volts. As the accelerating potential is increased the effect becomes principally one of radiation though some ionization is no doubt present. Ionization begins to increase at about 15.0 volts on the ratio curves. Adding the correction (− 1.4) to 15.0 gives 13.6 volts as the potential at which ionization begins to supercede radiation. At this potential the ratio begins to decrease rapidly from 4 until it reaches a value of almost 1.0 at 17.0 − 1.4 = 15.6 volts.

Final Results.

Radiation and some ionization was found at	10.1 ± 0.1 volts.
Radiation predominates between	10.1 to 13.6 volts.
Ionization begins to increase at	13.6 volts.
Strong ionization begins at	15.6 volts.

It is interesting to compare these values with those given by the Bohr theory for hydrogen.

Bohr's theory gives:

Resonance potential	10.16 volts.
Ionization potential of the atom	13.54 volts.
Ionization potential of the molecule	16.26 volts.

There is good agreement between the radiation and resonance potentials, and the first ionization potentials. But the strong ionization found at 15.6 volts does not check quite so well with 16.26 volts as predicted by Bohr's theory. Compton and Olmstead,[1] who first used the ratio method, give 10.8 volts for the resonance potential, 13.4 volts an additional critical velocity, and 15.9 volts the point where intense ionization sets in. The latter two values check fairly well with those found, but there is considerable difference between 10.8 and 10.1 volts.

2. *Nitrogen.*

Nitrogen gas was prepared by heating a solution of ammonium chloride and sodium nitrite in a hot water bath. It was passed through a red hot copper coil and collected against pressure in a storage tank. As before an air tight connection through a calcium chloride tube was used for admitting the gas into the apparatus. Phosphorus pentoxide and liquid air removed the other impurities. The spectrum checked well with that given by Georges Salet in his "Analyse Spectrale."

Some trouble was experienced at first due to what has been called by some writers, polarization effects. Difficulties of this nature have been reported by other observers for various gases. The nature of the trouble seems to be obscure. The character of the resonance and Lenard curves was not affected, but some of the first ratio curves showed that the gauze apparently received more current than the disc. This is difficult to account for, unless the disc was exposed a long time to a freshly coated filament, and some kind of an insulating layer was deposited on it. However this trouble was eliminated by removing the filament base, recoating the filament, and heating all platinum parts to a white heat with a gas flame. The electrodes were replaced and the movable electrode was bombarded by electrons from the hot cathode by applying a potential difference of 50 volts. This trouble was never repeated in the subsequent work.

[1] PHYSICAL REVIEW, Vol. 17, No. 1, Jan., 1921, p. 45.

Fig. 4 shows the type of results obtained. Curve 3 shows three distinct resonance points. In some of the curves four resonance points were obtained. This curve gives a resonance potential between the first two peaks of 8.4 volts. Subtracting from this value the value at which the first resonance point begins, gives an initial correction of -3.2 volts, which as explained before takes care of all corrections. The Lenard curve 3*a*, at the same pressure (0.4 mms.), gives the first indication of current at 11.5 volts, and a sharp change in slope due to ionization at 19.0 volts. Adding the correction, -3.2 volts, gives 8.3 volts for the resonance potential and 15.8 volts for the ionization potential.

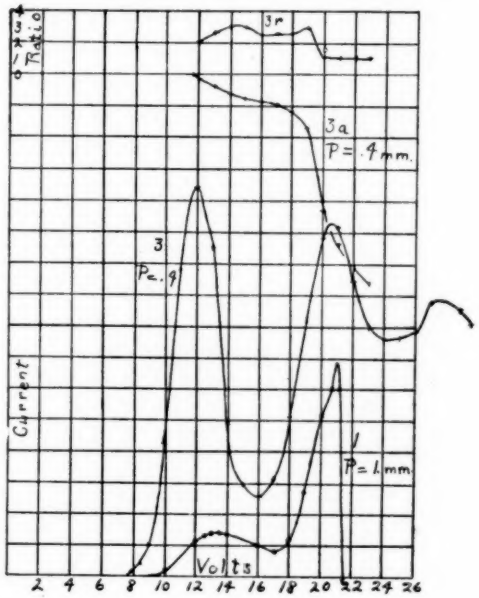

Fig. 4.

Curve 3*r* shows the ratio of the plate to the gauze current. This ratio is greater than 1 up to 19 volts, where it suddenly drops to a value of 1. It however indicates some ionization as well as radiation before the ionization potential is reached.

Curve 1 shows the arcing potential. It gives a resonance potential of about 8.5 volts and a consequent initial correction of -3.5 volts. Adding this to the observed potential at which arcing sets in, 20.5 volts, gives the arcing potential as 17.0 volts. The retarding potential used for this curve was only 5 volts, yet here we have an interesting case in which the increase of the accelerating potential from 20.5 to 21.0 volts gives a complete reversal of current, the galvanometer indicating a large positive current instead of an electron current. The magnitude of the

current was too large to measure on the scale. An intense bluish glow was observed when this break in the current curve took place. By using lower pressures and smaller retarding potentials, curves of type 3 were obtained without arcing setting in.

Using the frequency corresponding to the wave-length, = 1492.8 Å., of the isolated doublet in the nitrogen spectrum, observed by Lyman,[1] in the quantum relation, $Ve = h\nu$, we obtain $V = 8.27$ volts. The potential, 8.3 volts, obtained agrees fairly well with this calculated radiation potential. The limiting spectral line corresponding to the ionization potential of nitrogen has not been identified. With the ionization potential of nitrogen equal to 15.8 volts, this limiting spectral line should have a wave-length equal to 782.0 Ångstrom units.

Final Results.

Resonance potential of nitrogen	8.4 ± 0.1 volts.
Radiation predominates between	8.4 and 15.8 volts.
Ionization potential of nitrogen	15.8 volts.

3. *Oxygen.*

An oxone generator was used to generate the oxygen gas, which was said to be 99.4 per cent. pure. It was collected in the storage tank and admitted into the apparatus through a calcium chloride tube. Sometimes the spectrum would show a red line corresponding with that of hydrogen, but this would soon disappear with a hot cathode. Figure 5

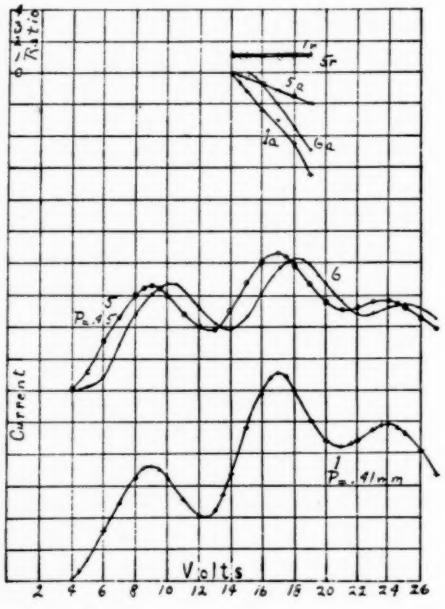

Fig. 5.

[1]Lyman, The Spectroscopy of the Extreme Ultraviolet, p. 113.

shows resonance, Lenard and ratio curves. The best resonance curves were obtained between pressures of 0.5 and 0.1 mm. Three resonance peaks were easily obtained. Curves 1 and 5 give resonance peaks starting at 8, 16, and 24 volts. The true resonance potential is then 8 volts, and there is no initial correction to apply to the corresponding Lenard and ratio curves. Hence the Lenard curves, 1*a* and 5*a*, give the ionization potential as 14.0 volts. It will be noted that no indication of current was found before 14.0 volts. It was sometimes thought that an indication of current could be detected at 13.7 volts, but this is not certain. The increase at 14 volts however was very definite. There is no indication of another ionization potential in the Lenard curves at a higher potential. Mohler and Foote[1] found resonance at 7.9 volts, ionization at 15.5 volts, but no Lenard indication of current before 15.5 volts. The resonance potential checks with that found in this investigation, but there is a difference of 1.5 volts in the ionization potentials. Hughes and Dixon[2] obtained what they called an ionizing potential at 9.2 volts for oxygen. They also state that the curve rises slowly from the axis for several volts, then begins to increase more rapidly. So that it is possible that there is a radiation or ionization effect before 14 volts which is too feeble to be detected in the Lenard method by the galvanometer used. The ratio curves give a value of 1.0 for all accelerating potentials, which means that the current is principally due to ionization from 14 volts on.

Curve 6 was taken immediately after Curve 5. The shift in the position of the curve was caused by reversing the direction of the heating current through the cathode. With Curve 5 the negative end of the accelerating potential was applied to the plus side of the cathode, and reversing the heating current for Curve 6, was the same as applying the accelerating potential to the negative side of the cathode. The resonance peaks of Curve 6 occur at accelerating potentials of about 1.2 volts greater value than those for Curve 5, and this was found to be equal to the potential drop along the filament due to the heating current. Hence we see that the accelerating potentials as read from the voltmeter for Curve 5 are about 0.6 volt less and those for Curve 6 are about 0.6 volt greater than they would have been if there was no potential drop along the filament.

Curve 6 gives 8.0 volts for the resonance potential, and an initial correction of about $8.0 - 9.0 = -1.0$ volt, which added to the corresponding Lenard Curve 6*a*, gives 14.0 volts for the ionization potential, which agrees with the values obtained from the other curves.

[1] Bureau of Standards Publications, No. 400, Oct. 14, 1920.

[2] PHYSICAL REVIEW, Vol. 10, No. 5, 1917, p. 502.

Final Results.

Resonance potential of oxygen	8.0 volts.
Radiation was not detected at any potential.	
Ionization potential of oxygen	14.0 volts.

4. *Ether* ($C_4H_{10}O$).

Ethyl ether, prepared by Squib for anaesthesia purposes, was poured into the special bulb for admitting the vapors. With the ether frozen by liquid air, the gas above it could be pumped out to a pressure of less than .00075 mm. Then by closing the three way stopcock to the bulb and removing the liquid air, the vapor could be admitted as desired. Pressures between 0.2 and 0.6 mm. gave the best results.

Figure 6 shows some typical curves. Curves 1 and 2 give resonance

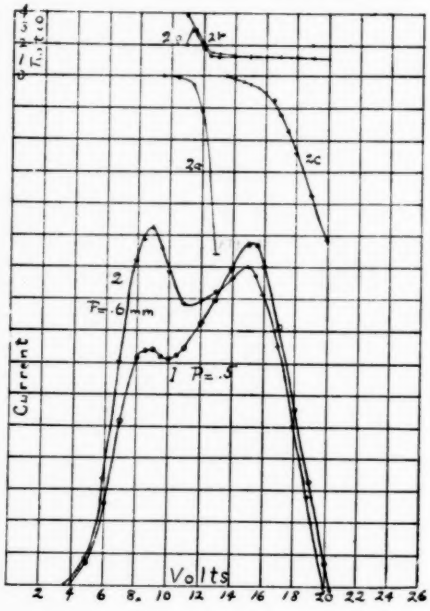

Fig. 6.

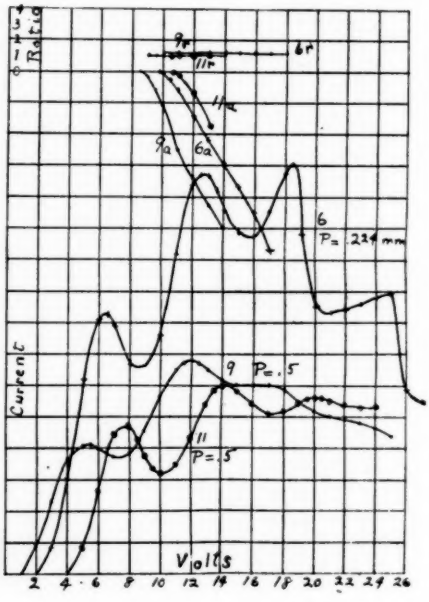

Fig. 7.

potentials of 6.6 and 6.7 volts respectively. The initial correction is − 1.4 volts. Beyond the second resonance point the current decreases rapidly, passes the zero axis and increases in the opposite direction. This effect is supposed to be due to two causes; one a large production of positive ions by ionization by collision, and the other, a decomposition or a chemical action of some kind taking place. It was found that the electron currents were steady in value until the second resonance point was passed. At this point the current would slowly decrease even with a constant accelerating potential, a phenomenon which indicates that some other effect besides ionization by collision is present. It may be

in ether, a compound consisting of carbon, hydrogen, and oxygen, that some kind of decomposition takes place when the molecules collide with electrons having a velocity equivalent to the accelerating potential at which the second resonance peak is produced.

The Lenard Curve *2a* starts at 9.5 volts, and adding the corresponding correction of − 1.4 volts, gives 8.1 volts as the potential at which current is first indicated. Perhaps a more sensitive current measuring device would have indicated a current at the first resonance potential, 6.6 volts. There is a large increase in current at 11.5 − 1.4 = 10.1 volts. Curve *2c* was taken at a lower cathode temperature and it shows a rapid increase at about the second resonance point, 15.0 − 1.4 = 13.6 volts. It is interesting, too, that at large values of accelerating potential, the Lenard currents also decrease with time.

The ratio curves indicate both radiation and ionization up to about 11.5 volts. From here the ratio decreases to a value of 1.0 at 12.5 volts. It is noteworthy that, since oxygen and hydrogen are both constituents of ether, the first indication of the Lenard current, 8.1 volts, agrees with the resonance potential of oxygen, and the increase at 10.1 volts is very close to the resonance potential of hydrogen. Of course additional information will be required before we can determine just what part of the ether molecule is affected when radiation or ionization is produced.

Final Results.

Resonance potential of ether	6.6 ± 0.1 volts.
Radiation and ionization were found at	8.1 volts.
Ionization predominates at	10.1 volts.
Strong ionization was found at	13.6 volts.

5. *Benzene (Benzol)* (C_6H_6).

The benzene used was guaranteed to be of the highest purity and crystallizable by Merck and Co. The benzene vapor gave less trouble than ether. Very little time was required to obtain steady currents.

Fig. 7 gives typical curves for benzene vapor. No difficulty was experienced in obtaining four resonance peaks. It was found that with retarding potentials of 3 volts or more, only two resonance peaks could be obtained, for the electron current beyond the second resonance peak would decrease to zero value and increase in the opposite direction as in the case of ether. The first indications of resonance in Curve 6 are at applied accelerating potentials of 6, 12, 18, and 24 volts, which gives the resonance potential as 6.0 volts with no initial correction to be applied to the corresponding Lenard curves. Curve 9, obtained at a higher vapor pressure, gives first indications of resonance at 5, 11, and 17 volts

and thus a resonance potential of 6.0 volts and an initial correction of $6.0 - 5.0 = + 1.0$ volt.

The corresponding Lenard curves, 6*a* and 9*a*, start at 9.7 and 8.5 volts respectively. Curve 6*a* needs no correction, while Curve 9*a* has an initial correction of + 1.0 volts to be added to 8.5 volts thus making it 9.5 volts. The Lenard curves give no further indication of a critical potential above 9.5 volts. The value of the ratio curves is approximately one at all accelerating potentials, which shows the effect is due principally to ionization.

Before taking the data for Curve 11, the cathode was removed and examined. It was found to be covered with a deposit of carbon, sootlike in appearance. A black deposit of this nature was never noticed while working with hydrogen, nitrogen, or oxygen. Subsequent removals of the cathode while working with xylene have also shown a black deposit. This deposit seems to give a fairly large supply of electrons. The cathode was then recoated with sealing wax and replaced. The curves taken immediately afterwards like Curve 11 required a larger applied initial accelerating potential to produce the first resonance peak than did Curve 9, which was taken at approximately the same gas pressure before the cathode was recoated. So that it would appear that an oxide coated filament requires a larger potential to separate the electrons from it than one with a carbon deposit. Subsequent removals and recoating of the cathode tend to substantiate this statement. Curve 11 gives resonance at 7, 13, and 19 volts and consequently a resonance potential of 6.0 volts, with an initial correction of $6.0 - 7.0 = - 1.0$ volt. The Lenard Curve 11*a* starts at 10.5 volts and adding the correction gives 9.5 volts as the ionization potential.

Final Results.

Resonance potential of benzene	6.0 volts.
Radiation was not detected at any potential.	
Ionization potential of benzene	9.6 ± 0.1 volts.

6. *Xylene* (C_8H_{10}).

Xylene vapor gave similar results to that of benzene. The currents were steady except at accelerating potentials of about 20 volts or more. At these higher potentials both the resonance and the Lenard currents exhibited decreases in value while at a constant accelerating potential. This indicates that some other effect besides ionization is present at these higher potentials.

Fig. 8 gives samples of the curves obtained with xylene vapor. In Curve 5 resonance begins to set in at accelerating potentials of 8.0, 14.5,

and 21.0 volts. This gives 6.5 volts as the resonance potential with an initial correction of −1.5 volts. Curve 2 shows only two resonance

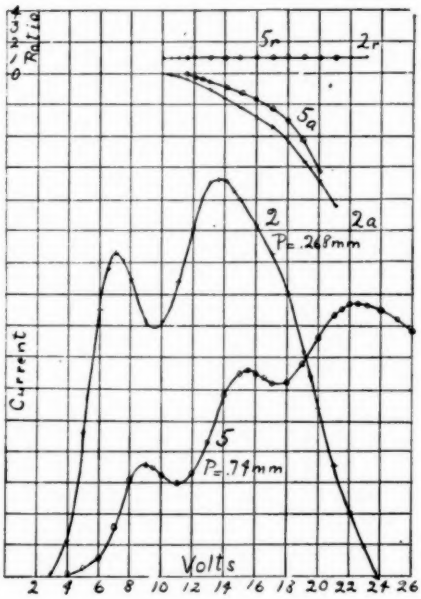

Fig. 8.

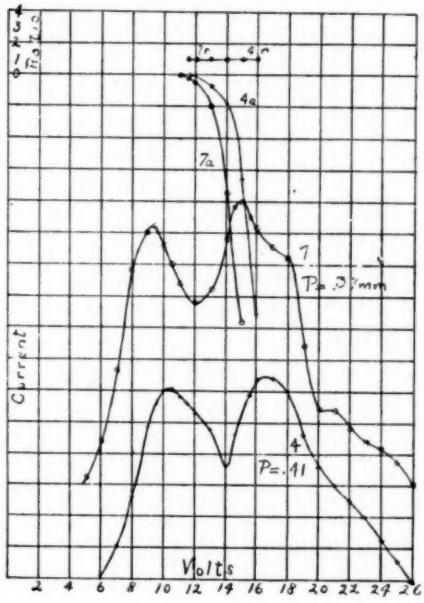

Fig. 9.

peaks beginning at 6.5 and 13.0 volts. The difference gives 6.5 volts as the resonance potential and no initial correction to apply to the corresponding Lenard and ratio curves.

Lenard Curve 5*a* begins at an accelerating potential of 11.5 volts and adding the proper initial correction, − 1.5 volts, gives 10.0 volts as the ionization potential. Curve 2*a* with no initial correction needed, also gives 10.0 volts for the ionization potential.

The ratio curves with a constant value of one, give no indication of radiation at any accelerating potential.

Final Results.

Resonance potential of xylene	6.5 volts.
Radiation was not detected at any potential.	
Ionization potential of xylene	10.0 volts.

7. *Toluene* (C_7H_8).

Some trouble was experienced while working with toluene vapor. The ionization tube had developed a leak, which necessitated the rebuilding of the glass stopper electrode assembly. With vapor present, a large initial accelerating potential of 5 to 6 volts was required to obtain a measurable electron current against a retarding potential of 1 or 2 volts.

The currents were steady until the first resonance peak was passed. Then they were somewhat erratic in their variations at a constant accelerating potential. Sometimes the current deflection would increase a few mms., then decrease a few mms., but always finally coming to rest at a definite position. It was impossible at any vapor pressure to obtain three resonance peaks, though curve 7 gives some indication of a third resonance peak at about 20 volts.

Some characteristic curves of toluene vapor are shown in Fig. 9. Curve 7 indicates resonance setting in at 8.5 and 14.5 volts, which gives a resonance potential of 6.0 volts with an initial correction of -2.5 volts. Curve 4 gives 6.5 volts for the resonance potential with an initial correction of $6.5 - 9.5 = -3.0$ volts.

Lenard Curve 4*a* starts at 11.5 volts and applying the proper correction gives 8.5 volts for the ionization potential. Curve 7*a* also gives $11.0 - 2.5 = 8.5$ volts.

The ratio curves give no indication of radiation. In fact, except for the large initial correction, toluene vapor behaves in a manner similar to that of benzene and xylene. These three belong to the benzene group, and therefore might be expected to give similar results.

Final Results.

Resonance potential of toluene	6.25 ± 0.25 volts.
Radiation was not detected at any potential.	
Ionization potential of toluene	8.5 ± 0.5 volts.

8. *Chloroform* ($CHCl_3$).

Commercially pure chloroform was used during this test. The filament had been freshly coated before admitting the vapor. After working several hours the filament was examined and no traces of carbon deposit could be detected. The electron currents obtained in chloroform vapor were always steady and apparently no decomposition of the vapor took place.

Fig. 10 shows some typical chloroform curves. Curve 2 gives a resonance potential of 6.5 volts with a correction of $+1.0$ volt, and likewise Curve 4 gives a resonance potential of 6.5 volts with a correction of $+1.5$ volts.

The Lenard Curves 2*a* and 4*a* give respectively 10.5 and 10.0 volts, both of which with the proper corrections, give 11.5 volts as the ionizing potential at which the Lenard current is first detected.

The ratio test gave a value of one for all accelerating potentials, showing that radiation was not present in a measurable quantity.

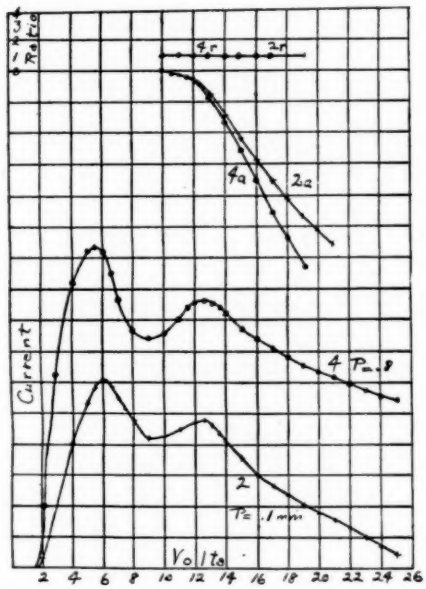

Fig. 10.

Final Results.

Resonance potential of chloroform	6.5 volts.
Radiation was not detected at any potential.	
Ionization potential of chloroform	11.5 volts.

The resonance potentials of hydrogen, nitrogen, and oxygen agree well with those obtained by Foote and Mohler,[1] who used the same method. The ionization potentials of these three gases as found in this investigation using the Lenard method, are respectively about one volt lower than those given by Foote and Mohler. This discrepancy may possibly be attributed to the method of making initial corrections, a difference in galvanometer sensitivity, and the design of the tube.

The indication of radiation in hydrogen as given by the ratio curves agrees well with that given by the ratio curves of Compton and Olmstead.[2] Strong radiation was found to predominate between the resonance and ionization potentials of nitrogen, while no radiation was detected in oxygen.

[1] Scientific Papers of the Bureau of Standards, No. 400.

[2] Physical Review, Vol. 17, No. 1, Jan., 1921, p. 45.

E. CONCLUSION.

Table of Results. (*In volts.*)

Gas or Vapor.	Resonance Potential.	Radiation Predominates.	Ionization Potential.
Hydrogen—H_2	10.1 ± 0.1	10.1 to 13.6	13.6 15.6
Nitrogen—N_2	8.4 ± 0.1	8.4 to 15.8	15.8
Oxygen—O_2	8.0	No radiation detected.	14.0
Ether—$C_4H_{10}O$	6.6 ± 0.1	8.1 to 10.1	13.6
Benzene—C_6H_6	6.0	No radiation detected.	9.6 ± 0.1
Toluene—C_7H_8	6.2 ± 0.25	No radiation detected.	8.5 ± 0.5
Xylene—C_8H_{10}	6.5	No radiation detected.	10.0
Chloroform—$CHCl_3$	6.5	No radiation detected.	11.5

So far as is known the critical potentials of the vapors used have not been heretofore determined. The resonance potentials for the vapors have about the same values, all lying between 6 and 7 volts. The ionization potentials also occur at a limited range of accelerating potential lying between 8 and 10 volts. Radiation was detected only in the case of ether. If it is present in the other vapors it is too small to be detected by the method used.

It should be noted that the results of this investigation indicate that in many cases inelastic collisions between the electrons and atoms take place without a measurable quantity of radiation being given off. Either this is due to a lack of sensibility in the detecting device, the method of measurement used, or the energy absorbed by the atom from the colliding electron is dissipated in some unknown manner.

Hughes and Dixon [1] found the ionization potentials of acetylene C_2H_2, methane CH_4, ethylene C_2H_4, and ethane C_2H_6, to be between 9.5 and 10.0 volts, which is of the same order as the ionization potentials of the vapors measured in this investigation. So that the hydrocarbons so far measured have approximately the same ionization potential.

The ionization potentials of the compounds are less than those of the simple elements of which they are composed. At least they are less than those of hydrogen and oxygen, the ionization potential of the carbon molecule not being known. This result might be expected from a consideration of the theory of the structure of the molecule. For

[1] PHYSICAL REVIEW, Vol. 10, No. 5, Nov., 1917, p. 495.

instance in a molecule containing a large number of electrons, the repulsive forces of neighboring electrons acting on any one electron will weaken the attractive force between it and the positive nucleus. So that such a molecule could be caused to give up one of its electrons with a smaller input of energy than a molecule containing say, only one or two electrons. No definite conclusions can as yet be drawn as to what part of the molecule is ionized. The loss of an electron by a molecule may mean a rearrangement of the remaining electrons about the nucleus, or it may mean the loss of an electron from one particular atom in the molecule.

In concluding the writer wishes to express his thanks to Dr. H. A. Wilson, under whose direction this investigation was carried out.

THE RICE INSTITUTE,
HOUSTON, TEXAS.
May, 1921.

MULTIPLE VALENCY IN THE IONIZATION BY ALPHA RAYS.

BY T. R. WILKINS.

SYNOPSIS.

Valency of Ions Produced by α-rays.—The well-known Millikan oil-drop method, in which the valency of individual ions caught on the droplet immediately after they are produced is determined by the change of speed of the droplet due to each, was used with slight modifications which simplified the procedure. *In air*, out of 350 positive ions produced by x-rays at the end of their range, only 3 per cent. could have been doubly charged and most if not all of these were probably not doubles but two successive singles. *In helium*, an extensive series of 2,150 positive catches were observed with gradually increasing pressure to determine not only whether doubles were produced but also the *variation of the number of doubles with the range.* It was found that an appreciable proportion of real doubles is produced when the ranges of the rays are equivalent to between 4 and 30 mm. of helium at atmospheric pressure, the maximum proportion being about 10 per cent., for the range of maximum ionizing power. That this result was real was proved by the fact that when *hydrogen* was substituted, even for the range of maximum ionization, the proportion of apparent doubles was only 5 out of 200 positive ions. The previously reported negative result for *mercury dimethyl* was confirmed.

Relative stopping power for α-rays, of air and helium, came out close to 3.8, in agreement with the Bragg-Kleeman law.

INTRODUCTION.

THE nature of the process of the ionization of gases by alpha rays was investigated by Millikan, Gottschalk, and Kelly [1] by catching an ionized molecule upon an oil-drop at the instant of ionization and then measuring the charge thus added to the drop. The results prove that at least 99 times out of 100, ionization by an alpha ray, in the case of the following gases and vapors (air, carbon dioxide, carbon tetrachloride, methyl iodide, and mercury dimethyl), consists in the detachment of a single electron from a molecule.

These results, along with much other work, summarized by Millikan, Gottschalk and Kelly, point to the formation of univalent ions. Indeed the only evidence for the formation of multivalent ions was the positive ray work of Sir J. J. Thomson.[2] Millikan pointed out, however, that these results were not at all irreconcilable, as a consideration of the velocities and the forces involved, made it conceivable that slow positive rays might make multivalent ions when fast alpha rays would not. It

[1] R. A. Millikan, V. H. Gottschalk, M. J. Kelly, PHYS. REV., 15, 157, 1920.

[2] J. J. Thomson, Rays of Positive Electricity and their Application to Chemical Analysis. Longmans, Green & Co.

became desirable, therefore, to test this point and, accordingly, such work has been undertaken.

Reference was also made to the scintillation experiments of Sir Ernest Rutherford on the "swift atoms" resulting from ionizing gases by the nuclear impact of alpha rays, in which the inference was drawn from negative, rather than positive evidence, that doubly charged ions of helium were formed. The importance of extending the oil-drop experiments to include a study of the alpha-ray ionization of helium was obvious, both because of the fundamental rôle played by the helium atom in the present-day theories of atomic structure and the fact that in alpha rays themselves we really have doubly charged helium ions. Recently it has become possible to secure helium in sufficient quantities for use in the oil-drop apparatus, the chamber of which has a volume of about twenty litres, and the results of a study of the alpha-ray ionization of helium are here given.

The results in helium, as will appear, made it seem desirable to extend the work to hydrogen, and this has also been done.

APPARATUS.

The apparatus used was identical with that already described [1] except that polonium was used instead of radium bromide as a source of alpha rays. Unfortunately polonium was not available at the time of the earlier work. While not altering the procedure in any way, this substitution brought two advantages: first, it removed the annoyances encountered in the earlier work which were caused by the formation of an "active deposit" on the walls of the chamber, and the consequent increased and uncontrollable ionization due to this cause; secondly, it provided a "simple" source of ionizing rays for which a random distribution of ejection could be assumed in a study of the frequency of catches.

The polonium was prepared by Mr. E. T. Johnson and Mr. B. A. Rogers, who also conducted some observations on the ionization of air, to which reference will be made later. To obtain the polonium some old radium preparation was used and the usual method followed.[2] The product was tested in an electroscope for the presence of beta rays by covering it with sufficient aluminum foil to absorb the alpha rays but not the beta rays, and it was found free of beta radiation.

The coarse adjustment to obtain ionization at the end of the range was made by interposing absorbing foil of the necessary thickness and the finer adjustment made by varying the gas pressure in the chamber. In this way a very delicate adjustment could be obtained.

[1] R. A. Millikan, V. H. Gottschalk, M. J. Kelly, loc. cit.

[2] Practical Measurements in Radioactivity, W. Makower and H. Geiger, Longmans, Green & Co., p. 123.

A concentrated filament lamp replaced the arc used in the earlier work and gave a very steady illumination and did away with the necessity of frequent adjustments of the arc.

A potentiometer switch was arranged so that the plate voltage could be varied through wide ranges in steps of 15 volts.

PROCEDURE.

The general procedure followed was that already described.[1] For the greatest possible simplicity of observation it was always arranged to have but one charge on the drop when the polonium door was open.

The field between the condenser plates was adjusted to balance the drop when it had this one charge on it and measurements were made at this one voltage. Thus the duties of the experimenter were very much lightened. As soon as a catch was made and measured, the drop was made ready for another catching by getting rid of all but one charge. This was done in the usual way.

The experimental testing of the number of charges on the drop is very simple under this procedure for there is then clearly an exact multiple relation between the characteristic speeds corresponding to various numbers of charges. And, further, no time is wasted in first determining the characteristic speeds or in redetermining them as the voltage of the cells drops, for if the voltage drop, the potentiometer switch is moved a peg till the original balance is secured. This was of help in the work on mercury dimethyl vapor, where the temperature was raised considerably to raise the vapor pressure while a run was in progress. No confusion resulted, for although the numerical values of the speeds changed, each one altered so that a multiple relation again held. For example, the speed corresponding to a catch of one charge changed from 16 to 18 seconds as the temperature and vapor pressure rose. That corresponding to a catch of a double rose, proportionately, from 8 to 9 seconds, and similarly, the triple speed changed from 5.3 to 6 seconds.

To express these relations in mathematical form, we have the two following equations:

(1) $V_0 = kmg$ where V_0 = the vel. of fall under gravity.
k = a constant of proportionality.

(2) $V = k(neE - mg)$ V = vel. of rise when the drop has a positive charge.
n = number of charges on drop.
e = the elementary charge.
E = the P.D. between condenser plates.

[1] Millikan, Kelly and Gottschalk, loc. cit.

Now, if $Ee = mg$, *i.e.*, if the potential applied is just sufficient to balance a drop with unit charge, (2) becomes,

$$V = k(n - 1)mg. \tag{3}$$

and so if

$$n = 1, \quad V = 0.$$
$$n = 2, \quad V = kmg.$$
$$n = 3, \quad V = 2kmg.$$
$$\text{etc.}$$

thus, when a charge is caught, the drop will start upward with a speed equal to kmg—if two charges are caught, with twice that speed; and if three charges are caught, with three times that speed, and we immediately have the number of charges caught because of this multiple relationship in speeds.

As evidence of the careful balancing of the drop and the control of the ionization, it may be mentioned that the drop was often left suspended for intervals of a quarter to half an hour and in one case a drop was left for an hour and a quarter and was in practically the same spot when the observers returned from dinner.

An attempt was made to take as long runs as possible on the same drop and in no case have fewer than 21 catches been reported on the work in air and in the work in helium not fewer than 50 catches of positives. As many as 150 catches are reported on some drops corresponding to from six to eight hours' observation on the same drop. Most of the drops remained bright right up to the end of the run, but in the work on mercury dimethyl vapor, where an attempt was made to raise the vapor pressure by raising the temperature some 15 or 20 deg. C., the drops soon lost their lustre and only short runs were possible.

DATA—AIR.

TABLE I.

Drop Number.	Pressure (Cm. of Hg).	t_g (Secs.).	Total No. of Catches (Pos. Negatives).	Double Positives.
1	8	103	95	2
2	8.1	95	21	0
3	8.1	150	68	1
4	8.05	102	35	0
5	8.1	105	108	0
6	8.15	114	66	3
7	8.3	103	21	0
8	8.15	138	48	2
9	8.2	110	52	2
			514	10

Table I. shows that out of 514 catches, 350 of which were positives, 10 were apparently doubles. It will be noted that the work here summarized was all done at approximately the same pressure. About as many more data were first taken under various conditions of pressure to determine the most suitable value at which to work. If the pressure is a little too low, too many alpha particles get through and the catches come too frequently. If the pressure is too high, the interval between catches becomes too long. It was thus found desirable with rays already slowed down by aluminum foil to the extent these were, to work with air at pressures between 8 and 8.5 cms. This corresponded very nearly to the end of the range of the alpha rays.

The column t_g represents the time taken for the drop to fall 50 scale divisions, approximately 5 mm., under gravity and thus indicates, roughly, the smallness of the drops.

In another set of observations of this same kind in air taken by other observers, namely Messrs. Johnson and Rogers, 519 catches of positive ions were made on 18 drops under approximately the same conditions as those just summarized. They found 15 catches which they counted as doubles and 5 which, though measuring up as doubles, they classed as "doubtfuls." By a doubtful double they meant that two jerks were observed in the drop's motion—a second jerk taking place before the shutter could be closed to prevent further ionization. While the second jerk might have been a Brownian movement jerk, as it often proved to be when measurement showed only a "single," yet it was felt that the second jerk might have been caused by the catching of a second ion and such catches were therefore classed as doubtful doubles.

It will be seen that these two sets of measurements are in very good agreement; Johnson and Rogers data showing about one double in 34 positive catches and the data here given showing one in 35.

To decide whether these were real doubles or whether a large fraction of these, too, were actually doubtful doubles, it was only necessary to find what was the average interval during which the polonium shutter was open before a catch was made and to calculate what the chance would be of two single ions being caught in an indistinguishably small interval. The observations showed that if the pressure was 8.1 cms. (in the case of air), the average exposure for a catch was 43 secs. but when the pressure rose, less than half a cm., to 8.5 cms. of mercury, the interval increased to 167 secs. and when a pressure of 9 cm. was reached, no catches were made after several intervals of ten or fifteen minutes, waiting. Hence, for alpha rays which had already been slowed down by the foil to the extent which these had, a pressure of between 8.1 and 8.5 cms.

of air enables us to make measurements at practically the end of the range. The discussion of the probability of two single ions being caught in an indistinguishably small interval is given below.

THE PROBABILITY FUNCTION.

It has been shown repeatedly that a random distribution of ejection can be assumed for the alpha rays emitted in radioactive changes. But it is a familiar result, taken from the theory of probability, that if a series of events happens with a random distribution of intervals, the probability of there being an interval as long as t seconds between two successive events is

$$P = e^{-ut}, \tag{1}$$

where $1/u$ is the average interval.

It was estimated that 1 second was a fair value to take for the time interval within which it was impossible to distinguish with certainty two successive catches as actually separate events for it required about this time for closing the shutter after a catch had been seen to have occurred and during the act of closing another catch might occur without being noticeable. In the various measurements made, the average interval varied from 13 to 170 secs. The probability function may be calculated for each interval but it will be legitimate for the purpose in hand, to consider only the general average, namely, 43 secs.

From (1), the probability of an interval as long as 1 sec. between two successive catches $= e^{-u}$. The probability that there will be an interval between 0 seconds and 1 second $= 1 - e^{-u}$. Now

$$e^{-u} = 1 - u + \frac{u^2}{2!} - \frac{u_3}{3!} + \text{etc.}$$

$$1 - e^{-u} = u - \left(\frac{u^2}{2!} - \frac{u_3}{3!} + \text{etc.}\right)$$

With $u = 1/43$, all terms of the last expression, save the first, are negligible, *i.e.*, the chance of two successive catches following within an interval of 1 sec. is simply u.

It appears then that since the average interval, as given below, is about 43 secs., that one catch in 43 under such conditions should appear as a double. This number is so near the total number of doubles obtained that we are justified in the assertion that no evidence is herewith presented for the formation of doubles in air. We may at least conclude with certainty that the act of ionization of air by alpha rays produces no more than two or three per cent. of doubly charged ions and practically never produces ions of larger valency than 2.

HELIUM.

It was decided to undertake quite an extensive investigation of helium as no work of this type had been done in that gas. Accordingly some 2,150 positive ions were caught; an attempt being made to approach *gradually* to the end of the range of the alpha particles. This was done by gradually increasing the helium pressure in the oil-drop chamber as successive oil drops were blown in with helium. As the "stopping power" of helium is much less than that of air, it was found that to slow down the alpha particles to the end of their range, a much larger helium pressure was required than was necessary in air. The gas pressure was steadily increased and measurements taken at various stages.

DATA—HELIUM.

It will be noticed from Table II. that the interval between catches decreased at first as the pressure was increased since more atoms of helium were present to be ionized. The interval became a minimum

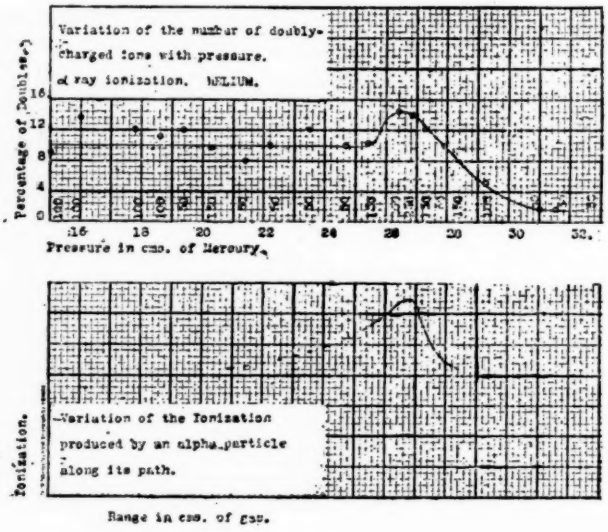

Fig. 1.

at a pressure of about 26.6 cms. and then gradually increased indefinitely. Thus the ionizing power of the alpha ray is a maximum a short distance from the end of its range, which is in agreement with other work. (See Fig. 1.) As the pressure was further increased, the number of alpha rays getting through was cut down and so the interval was lengthened.

TABLE II.

Press.	No. of Positives Caught.	t_0 of Drop.	Average Interval.	Per Cent. Doubles.	Average Per Cent. Doubles.	Range Beyond Point of Lip.*
8.9	50	74 secs.	44 secs.	2	2	4.0 cm.
13	50	73	23	4	4	3.3
15	100	112	19	9	9	
16	100	78	18	14	14	2.8
17.8	100	98	17	12	12	2.5
18.6	50	99	18	10	11	2.4
18.7	50	109	13.6	12		
19.4	50	113	20	12	12	2.3
20.1	50	127	21	16	9.3	2.1
20.3	50	108	27	6		
20.3	50	129	23	6		
21.4	50	141	20	8	8	1.9
22.2	50	127	31	10	10	1.8
23.5	50	124	28	12	12	1.6
24.7	50	130	27	10	10	1.4
25.4	100	140	26	9	10.5	1.3
25.5	50	143	26	12		
26.3	50	142	23	14	14.7	1.1
26.4	50	161	29	18		
26.6	100	155	17	12		
26.8	150	163	26	9	14	1.0
26.85	50	192	30	20		
26.9	100	139	23	13		
27.1	50	163	20	18	12	1.0
27.3	50	157	39	2		
27.5	50	174	31	16		
27.9	50	135	40	10	10	0.8
28.1	50	157	30	6	9	
28.4	100	171	28	12		
29	50	153	66	4	5	0.7
29.5	50	154	56	6		
30.95	50	138	67	2	2	0.3
31.5	50	155	88	2	2	
32.5	50	148	154	2	2	0.08
	2150					

The data show distinct evidence for the formation of doubly charged helium ions and show, moreover, that the formation of doubles does indeed depend on the speed of the ionizing particle. The number of doubles rises to a maximum when the ionizing power of the particles is a maximum and amounted, in this work, to as many as 15 per cent. of

* Reduced to atmospheric pressure. This reduction was suggested and outlined by Dr. G. S. Fulcher. It indicates that doubles are produced when the ranges of the rays are equivalent to between 4 and 30 mm. of helium at atmospheric pressure.

the number of ions formed. The probability of two singles being caught in an indistinguishably short interval would not account for more than three or four per cent. of the total catches being doubles, for the average interval at the peak of the production of doubles was about twenty-five seconds and thus, on the basis of the reasoning given above, one ion in twenty-five might be expected to be a spurious double. This still leaves a large margin for considering this a real effect, and this is made even more apparent in the light of some remarks under the head of hydrogen, below.

Grouping the data corresponding to pressures between 15 and 24 cms., it will be seen that the number of doubles is about 10 per cent. of the total number of positive ions produced, but from this region to the end of the range, a marked rise and subsequent decline is noticeable. Large fluctuations appear from this 10 per cent. but this is to be expected from any such probability measurement as this if only a small number of observations is taken. There seemed no special object in multiplying the observations in this region, but there was reason to expect that the region toward the end of the range might prove of special interest, for Geiger had shown, as is checked by the data above, that toward the end of the range the ionization rises very markedly.[1] Accordingly, a much larger number of observations was made in this region, and Fig. 1 shows that the curve is fixed quite definitely for this region of interest.

An interesting comparison may be made between the data on air and those on helium. It was found, as already noted, that with air, an interval of 167 secs. ensued between catches if the pressure were raised to 8.5 cms. Table II. shows that in helium an interval of 154 seconds accompanied a pressure of 32.5 cms. So the alpha particles were ionizing about as infrequently in one case as in the other. In other words, 8.5 cms. of air have about as great stopping power for alpha particles as 32.5 cms. of helium. This is in very nice agreement with Bragg and Kleeman's results that the stopping power of an element for alpha particles is proportional to the square root of the atomic weight and for complex molecules is an additive property.[2] Adams has already done work on the testing of this law for helium and other gases.[3] Using Adams's calculations for

$$\frac{\Sigma \sqrt{\text{At. Weight air}}}{\Sigma \sqrt{\text{At. Weight helium}}} = 3.8$$

and remembering that the stopping power is inversely proportional to

[1] Rutherford, Radioactive Substances and their Transformations, p. 153.

[2] Bragg and Kleeman, Phil. Mag., 6, 1905, p. 338.

[3] Adams, PHYS. REV., 24, 1907, p. 108.

the pressure, we calculate that the pressure of helium necessary to stop the alpha particles to the same extent as would be done by 8.5 cms. of air would be 8.5 × 3.8, or 32.3 cms. of helium. This is to be compared with the 32.5 cms. for approximately equal stopping power mentioned above.

HYDROGEN.

The law given by Bragg and Kleeman for the stopping power of gases for alpha particles has been shown, above, to be beautifully checked in the work on helium. It follows from the law, that hydrogen should have the same stopping power as helium, for though of different atomic weight, helium is monatomic and hydrogen, diatomic. If the doubles in helium were spurious in any way, the same effects should occur in hydrogen. A series of runs was therefore taken at that pressure at which the maximum effect was found in helium. Theoretically, there would be no expectation of doubles in hydrogen for the hydrogen atom is pictured as having but one electron and even though hydrogen is diatomic, the chance of catching a double, formed by the electrons being pulled off from each atom, would be negligible, for the positive nuclei remaining, would, presumably, at once repel each other and not be caught together. Commercial hydrogen was used.

TABLE III.

No. of Pos. Catches.	Press.	t_0.	Av. Interval.	Doubles.	Per Cent.
50.....	26.2	114	64 secs.	1	2
100.....	26.5	95	61	4	4
50.....	27	110	74	0	0
200				5	2.5

Thus hydrogen showed 5 doubles in 200 but since the probability calculation, as given above, would class 4 of these as spurious, it seems fair to conclude that not only were no real doubles secured in hydrogen but, because of the identity of stopping power and the conditions of temperature and pressure, the evidence is confirmed that those secured in helium were real and in no way due to faulty shielding, to the catching of two separately ionized molecules or to any such effects.

MERCURY DIMETHYL.

The work of Millikan, Gottschalk and Kelly was repeated in this case also but no evidence for real doubles was secured. The delicate adjustment for the end of the range could not be made, in the case of this

poisonous vapor, as with the other gases, so the vapor pressure was raised by raising the room temperature. The multiple relationship between the different valence speeds shown in the first part of the paper proved of great value here as the characteristic speeds constantly changed with the vapor pressure changes.

In conclusion, the writer wishes to thank Professor R. A. Millikan for outlining the problem and for his valuable suggestions during the course of the work. The present paper is but a continuation of Professor Millikan's earlier papers as has been indicated in the references above.

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ANALYSIS OF THE ENERGY DISTRIBUTION IN SPEECH.

By I. B. Crandall and D. MacKenzie.

Synopsis.

The frequency distribution of energy in speech has been determined for six speakers, four men and two women, for a 50-syllable sentence of connected speech, and also for a list of 50 disconnected syllables. The speech was received by a condenser transmitter whose voltage output, amplified 3,000 fold, was impressed on the grids of twin single stage amplifiers. The unmodified output of one of these amplifiers was measured by a thermocouple and was a known function of the total energy received by the transmitter, corrections being made for the slight variation with frequency of the response of the circuit. The output of the other amplifier was limited by a series resonant circuit to a narrow band of frequencies, the energy in this band being measured by a second thermocouple. The damping of the resonant circuit was so chosen that sufficient resolving power and sufficient energy-sensitiveness were obtained over the range from 75 to 5,000 cycles per second; and 23 frequency settings were made to cover this range. For each syllable simultaneous readings were recorded on the two thermocouples at each frequency setting. The consecutive syllables were pronounced deliberately by each speaker, maintaining as nearly as possible the normal modulation of the voice. Corrections were applied to offset the unavoidable variations in total energy incidental to repetition of a given syllable. 13,800 observations were made for all speakers. *The energy distribution curves* obtained are essentially the same for connected as for disconnected speech, and indicate that differences between individuals are more important than variations due to the particular test material chosen. A composite curve drawn from the individual curves shows a great concentration of speech energy in the low frequencies, a result which would not be expected from data previously published by others. The actual results contain a factor due to standing waves between the speaker's mouth and the transmitter, a complication always present in telephoning; this could not be eliminated.

The rate of energy output in speech for the normally modulated voice, was determined from the readings for total energy and was found to be about 125 ergs per second.

IN the study of speech and its reproduction by mechanical apparatus it is necessary to consider its composition from several different points of view. We desire first of all to know the actual frequency distribution of the total energy in speech, as well as the separate distributions for each individual sound. We also desire to know the apparent distribution of energy, that is, the distribution as perceived by the ear. Finally we wish to know the importance of each frequency, that is, the contribution to "articulation" or "quality" in the exact reproduction of speech which can be traced to the energy of each elementary band of frequencies in the speech range. In all three cases certain frequency

functions are used to represent these distributions. The advantage of considering these different frequency distribution functions separately has already been indicated by one of the present writers.[1]

In our judgment the most important of these data of speech study is the *actual energy distribution*, considering speech as "a continuous flow of distributed energy" in accordance with the ideas expressed in the earlier paper. The present paper offers a determination of this fundamental factor.

To determine the energy distribution in speech to a high degree of accuracy it would be desirable to analyze a certain amount of connected speech and take a time average of the energy distribution of the whole. This is not feasible at the present time, but a very close approach to this result has been made. The method consists in analyzing the speech waves as impressed on a condenser transmitter, using a tuned circuit to transmit narrow frequency bands of energy and pronouncing the separate syllables of the connected speech so slowly that the kick of a direct current galvanometer connected to an A. C. thermocouple can be separately read for each syllable. Using a suitable calibration for the whole apparatus, the magnitude of this kick can be interpreted in terms of the time integral of the energy at a particular frequency setting for each syllable. A mean of the readings for all the syllables in the "speech" at any frequency setting gives the relative energy at that frequency.

The present method is a modification of an earlier method in which approximate analyses of speech sounds were made, using a condenser transmitter, tuned circuit, an amplifying-rectifying circuit, and ballistic galvanometer. The method is, however, much improved as we now have very accurately calibrated condenser transmitters of better design,[2] and a great deal of care has been taken to calibrate the successive elements of the train of apparatus, and increase the resolving power.

Experimental Procedure.

Sound waves emitted from the mouth of the speaker are allowed to fall upon the diaphragm of a condenser transmitter, connected in the conventional manner to the input of a three-stage amplifier. The output of this is impressed upon the input circuits of twin single stage amplifiers, potentiometers being interposed to permit regulation of the grid voltages of the twin amplifier tubes.

The output circuits of the fourth stage consist of the high windings of two step down ironclad transformers. These step down transformers

[1] "The Composition of Speech," PHYS. REV., X., p. 74, 1917.

[2] The present design of the condenser transmitter and its calibration are fully treated in a paper by Dr. E. C. Wente which will appear shortly in this Journal.

have a voltage ratio of 11 : 1 and are designed to work between impedances of 6,000 and 50 ohms. The low impedance winding of one of these transformers operates into a thermocouple heater of, roughly,

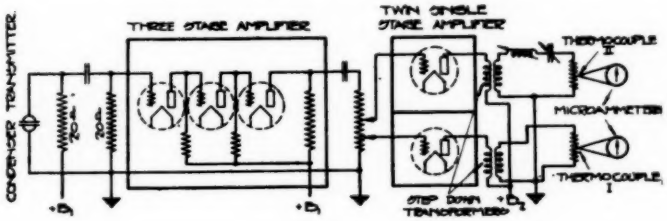

Fig. 1.

Circuit used for the analysis of speech. (The usual details of the three stage amplifier are not shown.)

40 ohms resistance. The low side of the other transformer operates through a tuned circuit into a similar thermocouple heater. The diagram of Fig. 1 exhibits the essential features of the electrical circuits just described.

When the diaphragm of the condenser transmitter is set in vibration by speech a current made up of a range of frequencies flows in the heater of thermocouple I., while the heater of thermocouple II. is traversed only by such a band of frequencies as the resonant circuit allows. Fig. 2 shows a number of typical resonance curves obtained in the course of

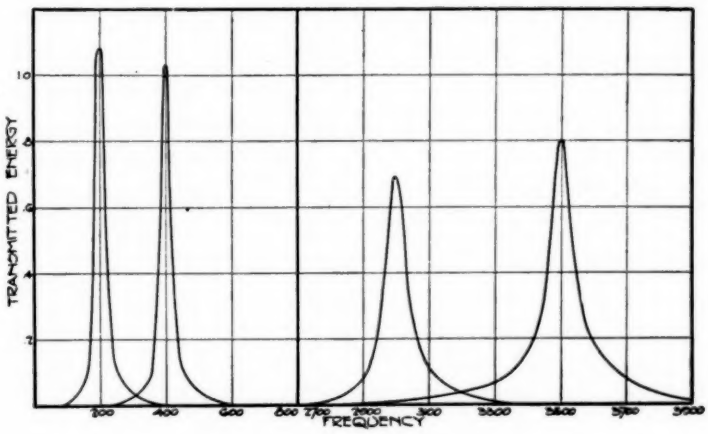

Fig. 2.

Resonance curves showing the resolving power of apparatus.

calibrating this apparatus. These curves are such that the tuned circuit functions as a filter transmitting only a narrow region of frequencies. One side of the twin amplifier transmits the entire electrical response of

the system; the other side suppresses all save a band of frequencies, the center of this band being shifted by resetting the condenser and inductometer.

Having chosen for analysis a piece of connected discourse, the speaker utters the successive syllables separately but as nearly as may be with the same inflection and volume as if the syllables were continuously spoken. Two observers record the readings of microammeters in the couple circuits of the thermocouples. One of these instruments gives a deflection corresponding to the total energy of the syllable uttered; the deflection of the other instrument corresponds to the energy of the syllable lying within the limits of transmission of the tuned circuit.

Preliminary experiments were carried out to determine the relation between momentary deflection read on the microammeter, and the current momentarily flowing in the thermocouple heater. Currents of different values were caused to flow for intervals of time varying from 0.2 second to 1.2 seconds, and the deflections were found nearly proportional to the product of current squared and time interval; this proportionality was most nearly exact when the current was weak and the time intervals short. For all cases likely to be duplicated in the speech analysis work the error might be taken as about 5 per cent., a quantity small in comparison with the inevitable uncertainties due to other causes.

Quite low damping is attained in the resonant circuit. The values of inductance used range from 0.20 to 0.66 henry and the total resistance of the circuit—transformer winding, inductometer coil, thermocouple heater—is of the order of 100 ohms. The damping thus ranges from 75 to 250.

The circuit is calibrated in the following manner:

A switch is so introduced that it is possible to include in series with the thermocouple, the resonant circuit, or replace it by a non-inductive resistance whose value is approximately that of the A. C. resistance of the inductometer winding. With the tuned circuit excluded, an alternating current of suitable magnitude is caused to flow in the thermocouple heater; the tuned circuit is then substituted and the new value of the current observed, the input voltage remaining constant. The ratio of current squared "tuned circuit in" to current squared "tuned circuit out" is plotted against frequency, yielding a curve for energy transmission.

Twenty-three bands in all were considered adequate for the analysis of energy distribution in speech; the centers of these were at 75, 100, 200, 300 cycles, 400 to 3,200 cycles by steps of 200; 3,500, 4,000, 4,500, 5,000 cycles per second. Beyond 5,000 cycles per second, the energy is

so low as to be impossible of measurement with the apparatus used. A Weston Type 322 microammeter recorded the couple current for the tuned circuit side of the twin single stage amplifier. With this instrument and the thermocouple used, 0.2 microampere in the couple circuit corresponds to one quarter of a milliampere in the heater, and this is the lowest readable deflection of the Weston instrument.

REDUCTION OF OBSERVATIONS.

Three corrections have to be made, the first being the correction for varying volume.

Simultaneous observations are made, at each setting of the tuned circuit, of the filtered and the unfiltered energy of each syllable. It is not possible to utter a given syllable with the same intensity and at the same distance from the transmitter for every one of twenty-three times. Accordingly, the "unfiltered" readings are averaged and each of the filtered readings for each syllable reduced from the value actually observed to the value that would have been read had the volume and distance been such as to give the average "unfiltered" reading. This procedure is quite legitimate if it be granted possible to maintain a definite composition of the syllable in question throughout the changes of the tuned circuit setting.

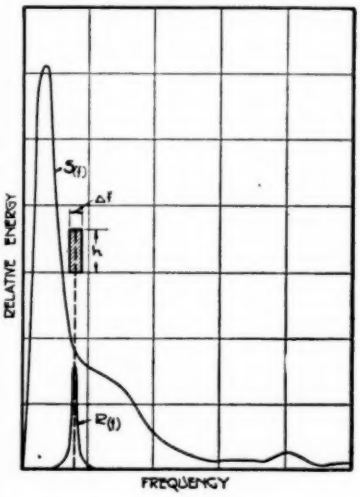

Fig. 3.

Illustrating correction of observations, necessary because of variation in resolving power with frequency setting.

A second correction was made for the varying area of tuned circuit curves.

In Fig. 3 let $S(f)$ be the speech spectrum determined by ideal methods; "R" the transmission curve of the tuned circuit, set for a resonant frequency f. An ideal transmission curve would be a rectangle when plotted in this figure, of height "h" and transmission range Δf.

The true amount of energy $S(f)$ associated with frequency f, and the experimentally determined value which we may call $S(f)$ are connected by the relation

$$h\bar{S}(f)\Delta f = \int_{f}^{f+\Delta f} S(f)R(f)df$$

and if we make

$$h\Delta f = \int_{f}^{+\Delta f} R(f)df$$

we may take for all practical purposes $S(f) = \overline{S}(f)$, considering the narrowness of the transmission range. We must therefore find the factor $h\Delta f$, proportional to the area of each tuned circuit curve and divide the energy received through the filtered side by $h\Delta f$, in order to obtain $S(f)$. This treatment may be gone through for each syllable individually, but it is more convenient to sum the tuned circuit readings for all the syllables used, corrected one at a time for varying volume, and then apply the curve area correction to this sum.

A third correction was made for the varying frequency-sensitivity of the whole apparatus. Thus far we have discussed only the electrical energy in the output circuit of the fourth stage. It remains to show in what way this is related to the mechanical energy of the diaphragm, and this in turn to the incident sound energy.

The calibration of the circuit as a whole was made by introducing a small resistance carrying alternating current in series with the condenser transmitter, thus introducing a known potential drop in the undisturbed input mesh of the circuit.

An amplification curve is appended (A, Fig. 4) which gives to an arbitrary scale the ratio of volts output to volts input as a function of frequency, for the system as actually operated. The calibration of the condenser transmitter, shown in Fig. 4, Curve C, gives the open circuit

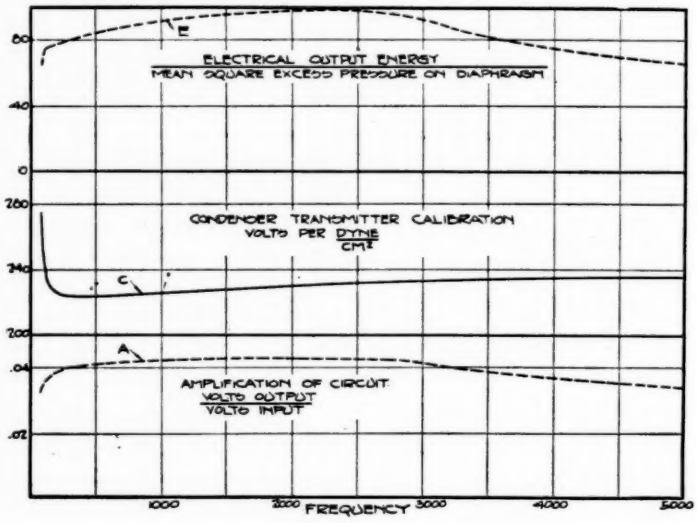

Fig. 4.

Energy-frequency characteristics of the apparatus.

voltage of the transmitter per unit pressure on the diaphragm, as a function of frequency. The product of these curves is the volts output

per unit alternating pressure on the diaphragm, and the square of this product, curve E is proportional to the electrical energy output per unit sound energy incident on the diaphragm, if we assume that the sound energy is proportional to the square of the alternating pressure. This point, however, requires some further discussion, which will be given later on.

It is plain from curve E that the response of the system is a maximum for frequencies in the neighborhood of 2,250 cycles. If, now, the observations already corrected for varying volume and for area of resonance curves, are subjected to further correction for the exaggeration of these frequencies, it is possible to draw a curve which shall exhibit the mean square of the excess pressure on the diaphragm, as a function of frequency in the voice exciting the vibration. We obtain this corrected curve by dividing the results, after the first and second corrections above have been made, by the ordinates of curve E.

Observations.

In order to investigate the possibilities of this method it was decided to work with a rather short piece of connected speech, and to use a limited

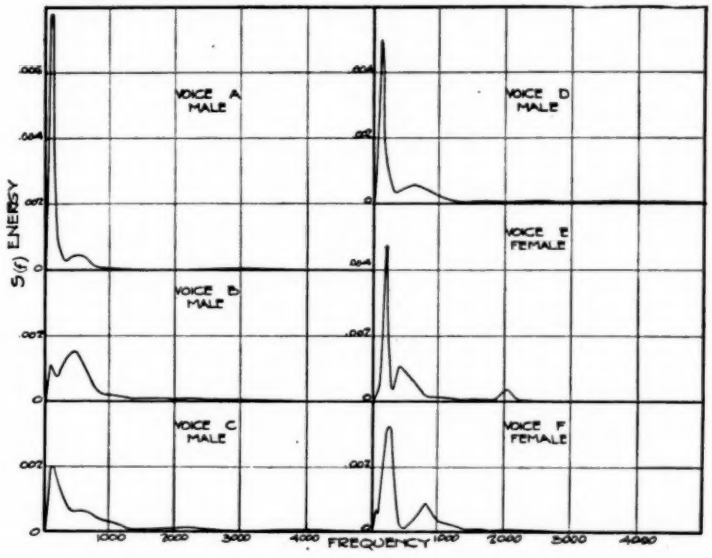

Fig. 5.

Analysis of individual voices.

number of observers, on account of the large number of observations which are required for each separate syllable. With six speakers (four men and two women) each pronouncing the test sentence of fifty syllables for each of the twenty-three frequency settings, 6,900 separate observa-

tions were required. It is believed that representative results have been obtained from these observations, but if this is not the case then some method of graphical registration of the energy-time curve of speech for the different frequency settings must be applied in order to handle the vast amount of data involved in work on an appreciably larger scale.

The test sentence used was as follows:

"*Quite* four score and seven years ago our fathers brought forth on this continent, a *nice* new nation, conceived in liberty, and dedicated to the proposition that all men are created equal."

The two *italicized* words were added to the first sentence of the "Gettysburg Address" in order to bring the total up to fifty syllables, and improve the balance between the vowel sounds.

The resulting speech-energy curves are shown in Figs. 5, 6 and 7,

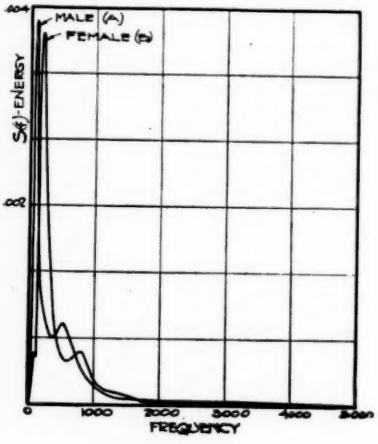

Fig. 6.

Energy distribution: composite curves of male and female voices.

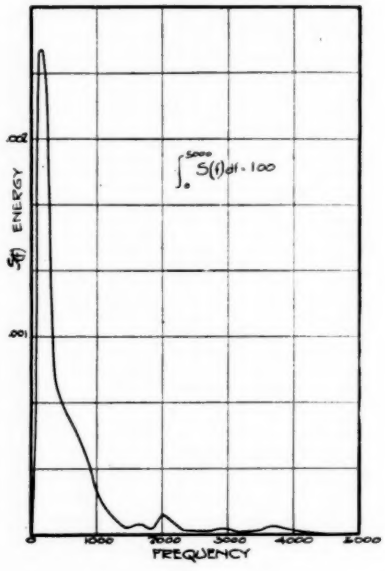

Fig. 7.

Energy distribution: composite curve for all voices.

plotted so that $\int_0^\infty S(f)\,df = 1$ in each case. In Fig. 5 the individual curves for each of the six speakers are shown on a small scale; in Fig. 6 the composite curve for the men and the composite curve for the women, drawn separately, and in Fig. 7 the composite curve for all six speakers, giving the data of curves 6*A* and 6*B* equal weight.

These curves are very similar to a curve obtained by Dr. Fletcher of this laboratory, using block filters and based on the simple calling sentence "Now we're off on one." A general consideration of this fact and of

the data shown leads us to believe that the differences between curves of this sort, made by the method described are due rather more to differences between the voices of the individual speakers than to the particular piece of connected speech which is chosen, provided the speech is of reasonable length. The differences between the different voices are so marked that we should expect them to remain even though we used as test material a connected speech ten or fifty times as long as the sentence used.

THE ENERGY DISTRIBUTION IN SPEECH.

An interesting comparison may be made between the curves shown for the energy distribution of "continuous speech" and certain speculative curves previously constructed to indicate the energy distribution. One of these curves is shown in Fig. 8. Curve *A* was constructed by one

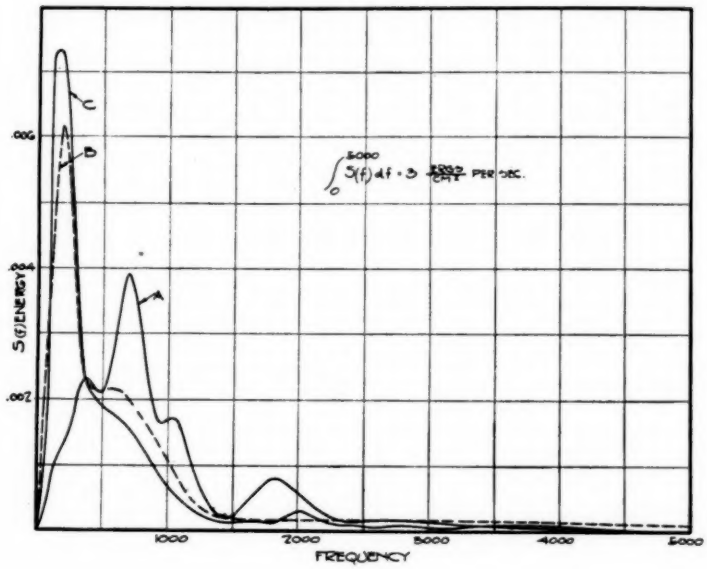

Fig. 8.

Energy distributions: *A*. Synthesized from vowel records of D. C. Miller (1916). *B*. Disconnected speech analysis of this paper. *C*. Connected speech analysis of this paper (from Fig. 7).

of the writers in 1916 in an attempt to synthesize the energy curve from the energy distributions of the vowel sounds, using the vowel analyses of Dr. Dayton C. Miller. Curve *C* is the composite "continuous speech" curve of Fig. 7. The vowel sounds analyzed by Miller were intoned and the vowel sounds analyzed by us were spoken, but Miller's work seemed to show that there was no essential difference between intoned and spoken vowel sounds. There is, however, a very noticeable difference between

Curve *A* and Curve *C*, the energy in the fundamental tone of the speaker's voice coming out much more strongly in Curve *C*. We should expect that our improved apparatus would record the energy in the lower frequencies more correctly than the apparatus heretofore used but as we used different test material (connected speech instead of disconnected syllables or vowel sounds) it is not immediately evident which of these two factors is responsible for the differences between the *A* and the *C* curves.

In order to investigate this point more fully the testing routine for all six speakers was repeated, using instead of the fifty-syllable sentence, the fifty disconnected syllables of one of the standard articulation testing lists, as used by Dr. Fletcher in this laboratory. The results for energy distribution are shown in Fig. 9, Curve *A* being the mean energy distribution for the four male speakers, using the syllables, while Curve *B* is the mean energy distribution for the two female speakers. Curves 9*A* and 9*B* may be compared with Curves 6*A* and 6*B* which represent the sentence of continuous speech. The two sets of curves are essentially the same as shown in Fig. 8, *C* and *B* being respectively the composite curves for all speakers, using connected and disconnected speech.

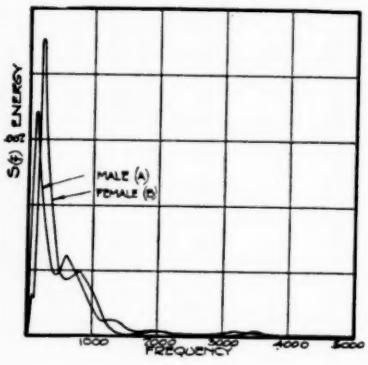

Fig. 9.

Energy distribution in disconnected speech.

Such small differences as exist between Curves *C* and *B* of Fig. 8 may probably be due to differences in the distribution of the vowel sounds in the connected and disconnected test material. This distribution is given in the following table:

Vowel Sounds.	a	ā	á	e	ē	ér	i	ī	o	ō	ó	u	ū	ou	Total
In Sentence.....	6	6	3	7	3	3	7	2	2	5	3	0	2	1	50
In Syllabic List (No. 174).	4	4	3	4	3	4	3	4	3	4	3	4	4	3	50

Key to Vowel Sounds:

a, as in father (or o as in top)
ā, as in tape
á, as in tap
e, as in ten
ē, as in team
ér, as in term
i, as in tip
ī, as in time
o, as in ton
ō, as in tone
ó, as in for
u, as in pull
ū, as in rule
ou, as in house

The similarity between Curves *C* and *B* of Fig. 8 is evidence of the general reliability of the method, and leads to two rather important conclusions.

In the first place, characteristic results have been obtained for a given set of speakers, using two different types of test material. This seems to show that the choice of test material does not require especial consideration, provided it is of sufficient length. It seems to be a matter of rather greater importance to increase the number of observers.

In the second place, it seems that for the actual energy distribution, the results previously obtained from the vowel analyses are definitely in error, in that they show relatively little energy associated with the lower voice frequencies.

CRITICISM OF THE RESULTS.

The foregoing treatment provides a curve showing the frequency distribution of the square of the excess pressure on the diaphragm.

In an undisturbed field of sound energy we have for the intensity

$$I = \frac{P^2}{2\rho a}$$

in which ρ is the mean density of the medium, a the velocity of sound in the medium and P the maximum excess pressure.

It remains for us to consider in how far the results obtained represent the frequency distribution of sound energy in speech.

Due to the fact that at frequencies where the sound wave-length is short and comparable with the diameter of the transmitter, considerable reflection takes place, and the pressure on the diaphragm is proportionately greater for these frequencies than for those which are not accompanied by strong reflection. In this respect again the higher frequencies provoke the greater response in the system.

The following experiment was tried to investigate this variation. A wall six feet square, with a central hole to fit over the condenser transmitter, was brought up to make the transmitter a part of a plane wall. The clearance around the periphery of the transmitter was tightly closed, and reflection was to be expected at all frequencies. Where total reflection takes place, a given quantity of sound energy results in twice the alternating pressure on the diaphragm as when no reflection occurs. That is, the resulting electrical energy observed should be four times as great for total reflection as for no reflection. The wall was expected to cause reflection at all frequencies, and the experiment consisted in reading the electrical response, with and without the wall, the condenser transmitter being exposed to tones of frequencies from 200 to 10,000

cycles per second under definite adjustments of the supply circuit of a receiver producing this tone. When the frequency is low, little reflection takes place from the transmitter standing alone, and bringing up the wall should cause a great increase in the response of the system. At high frequencies the transmitter should reflect nearly as much alone as when part of a large wall, and the readings with and without the wall should be nearly equal. Plotting ratio of response without, to response with the wall was expected to yield a curve which could be used to make the final reduction of electrical output to incident sound energy, and so permit a more accurate determination of the spectrum of sound energy of the voice.

No consistent results were obtained after several trials and the experiment was abandoned. The failure is doubtless to be ascribed to standing waves, the character of which is very sensitive to the location in the room of the transmitter and the wall. This experiment is to be repeated under more favorable conditions when standing waves can be eliminated.

Thus, the curves finally obtained show no more than the frequency distribution of energy in speech in terms of the mechanical energy of a more or less ideal transmitter diaphragm. However, this information has its value because in any given configuration of transmitter, speaker, and room, there is a definite correspondence between the sound energy of the voice and the force acting on the diaphragm on which it falls, and in telephony at any rate it is this action on the diaphragm with which we are immediately concerned.

In conclusion we may give a determination of the total energy rate of speech, obtained as a by-product of the preceding investigation. Knowing the calibration of the system in absolute units, it is possible to determine the alternating pressure on the condenser transmitter diaphragm exposed to continuous speech from the normally modulated voice under the conditions of the experiment. Using the mean of the values obtained with 9 observers we find for the alternating pressure 11.3 dynes per sq. cm. (r.m.s.) for a distance of 2.5 cm. from mouth to diaphragm. This corresponds to an energy flow of 3.2 ergs per sq. cm. per second. Assuming that this energy flow is distributed uniformly over a hemisphere of 2.5 cm. radius, we may take 125 ergs per second as the total sound energy flow from the lips with the normally modulated voice.

RESEARCH LABORATORY OF THE
AMERICAN TELEPHONE AND TELEGRAPH CO.,
AND THE WESTERN ELECTRIC CO., INC.

NOTE ON THE DISTRIBUTION OF RANGE OF RECOIL ATOMS.

BY K. T. COMPTON.

SYNOPSIS.

Number and Range of Recoil Rays, Produced by α-ray Bombardment, to be Expected on the Assumption of the Inverse Square Law of Force between Nuclei.—In calculating these quantities for comparison with his experimental results for hydrogen, Rutherford took account only of impacts occurring at the slit, whereas recoil rays may reach the screen from other points. In this note is given a method of calculating the exact number of recoil rays, for a given thickness of absorbing screen, to be expected with the experimental arrangement used for gases by Rutherford. The results for hydrogen come out about 30 per cent. larger than those computed by Rutherford; but this fact does not invalidate his conclusion that the difference between experimental and theoretical curves indcates a law of force other than the inverse square in the case of collisions by high speed α particles.

IN his paper on the collision of α particles with atoms of hydrogen,[1] Professor Rutherford has shown that, at the smallest distances between hydrogen nuclei and the fastest α particles, the force is no longer that of the simple inverse square, due probably to additional forces arising from the distortions of the nuclei. This conclusion was drawn from the observation that, for the fastest α particles, a larger proportion of the recoil atoms is projected with high velocity in the direction of impact than is predicted from theoretical considerations based on the inverse square law. The theoretical equation used does not correspond exactly to the actual experimental conditions, since it applies to a case where all the recoil atoms come from impacts occurring at the slit, whereas, in the actual experiments, recoil atoms come from certain regions in the volume of the gas as well as from the gas at the slit. More recently Professor Rutherford has called attention to this inaccuracy in his original treatment of the problem,[2] and Darwin[3] has indicated a method of correctly deducing, from experiments on the distribution of range of the recoil atoms, the nature of the force at the collision.

The present note outlines a direct and easy method of calculating the exact distribution of range to be expected with an experimental arrangement of the type used for gases, if the inverse square law of attraction holds true. It is, therefore, a special case of the problem treated by

[1] Phil. Mag., 37, p. 537, 1919.
[2] Phil. Mag., 41, p. 307, 1921.
[3] Phil. Mag., 41, p. 486, 1921.

Darwin, but is in a form convenient in application to cases where it is desired to detect departures from the inverse square law. Although a correction to Professor Rutherford's calculations, the result of the present treatment shows that the validity of his conclusions is in no way vitiated. Even the corrected calculations are far from agreeing with the experimental results, which shows that the law of force at the collisions of very high speed α particles with atoms is not that of the inverse square.

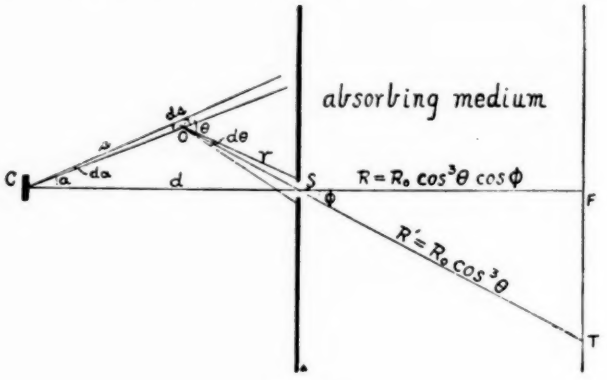

Fig. 1.

α particles leave the point C, traveling in all directions. The number of these leaving per second is N'. Of these,

$$Q = \frac{N'A}{4\pi d^2}$$

pass through the slit S, of area A at a distance d from C. Beyond S they pass through a slab of absorbing material of thickness equivalent to R centimeters of air, and strike the fluorescent screen F.

If hydrogen fills the region to the left of the slit, recoil atoms may be produced at any point O, and some of these will pass through the slit. They will strike the fluorescent screen if their velocity is sufficient to give them a range greater than the distance ST through the absorbing screen. The number n per second of these scintillating recoil atoms is counted, when the absorbing screen is more than thick enough to stop the α particles.

$\frac{1}{2}N' \sin \alpha d\alpha$ is the number of α particles leaving C in directions between α and $\alpha + d\alpha$ per second.

$2\pi N\mu^2 \tan \theta \sec^2 \theta d\theta$ is the fraction of the α particles which, in one centimeter path, produce recoil atoms at angles of recoil between θ and $\theta + d\theta$. Here N is the number of gas atoms per unit volume and

$$\mu = \frac{eE}{v^2}\left(\frac{1}{m} + \frac{1}{M}\right),$$

where e, E, m and M are the charges and masses of the recoil atom and α particle, and v is the velocity of the α particle.

$A \cos\phi/2\pi r^2 \sin\theta d\theta$ is the fraction of the recoil atoms, produced at O and starting in directions between θ and $\theta + d\theta$ with s, which pass through the slit.

Therefore, the product of these quantities leads to

$$n = \int_{\alpha=0}^{\alpha=\pi/2} \int_{s=0}^{s=s'} \tfrac{1}{2} N' N A \mu^2 \sin\alpha d\alpha \frac{\cos\phi}{r^2 \cos^3\theta} ds$$

as the total number of recoil atoms passing per second through the slit, where s' is so chosen that the recoil atom has such velocity and direction as to enable it just to reach the fluorescent screen.

Equations relating certain of the above quantities are

$$s \sin\theta = d \sin\phi,$$
$$r \sin\theta = d \sin\alpha,$$
$$\theta = \alpha + \phi,$$

by use of which the above equation may be written

$$n = \int_{\alpha=0}^{\alpha=\pi/2} \int_{\theta=\alpha}^{\theta=\theta_1} \tfrac{1}{2} N' N \frac{A}{d} \mu^2 \left(\frac{\cos\alpha}{\cos^2\theta} + \frac{\sin\alpha \sin\theta}{\cos^3\theta} \right) d\alpha d\theta,$$

where θ_1 is the largest angle of recoil at which the recoil atoms may reach the absorbing screen.

The integration with regard to θ gives

$$n = \int_0^{\pi/2} \tfrac{1}{2} N' N \frac{A}{d} \mu^2 \left(\tan\theta_1 \cos\alpha + \frac{\sin\alpha}{2\cos^2\theta_1} - \sin\alpha - \frac{\sin\alpha}{2\cos^2\alpha} \right) d\alpha.$$

The limiting value θ_1 is determined by the relation $R = R_0 \cos^3\theta_1 \cos\phi_1$, where R_0 is the maximum range of the recoil atoms and R is the equivalent thickness of absorbing medium, since the range measured normally through the absorbing screen is proportional to the cube of the velocity of recoil and to $\cos\phi$. This may be written

$$R/R_0 = \cos\alpha \cos^4\theta_1 + \sin\alpha \cos^3\theta_1 \sin\theta_1$$

and the value of θ_1 corresponding to any specified range R of the recoil atom may thence be calculated for any desired value of α.

The last integration is made graphically by evaluating first θ_1 and then the expression in parenthesis, for various values of α (R being fixed), plotting the values of the expression against α and taking the area under the curve. When this is done, and the known values of μ and N are substituted, and $4\pi Qd^2$ is substituted for $N'A$, the value of n/Qd is found for the particular value of R chosen. This process may then be repeated for other values of R.

In Fig. 2, the solid line shows the values of n/Qd for different values of R, calculated in the manner outlined above. The broken line shows the values calculated by the approximate equation used by Professor Rutherford. Both curves refer to recoil atoms produced by α particles whose range in air is 7 cm.

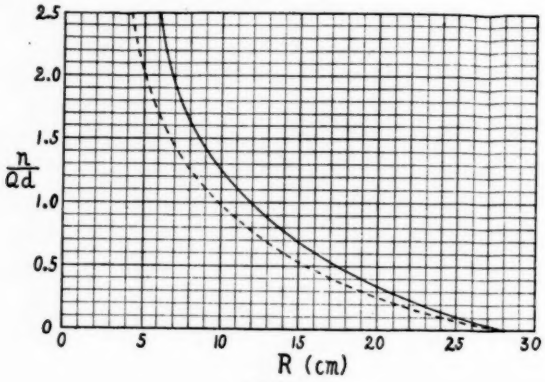

Fig. 2.

Since Professor Rutherford's conclusions regarding the nature of the forces at collision are drawn from a great difference between the shapes of the theoretical and the experimental curves for high velocity α particles, it is evident that they would not be modified by substituting the exact for the approximate theoretical distribution. For relatively slow α particles, however, the number of scintillations observed agrees better with the theoretical predictions as calculated above than with those calculated by the approximate equation, since Professor Rutherford found the observed number to be always somewhat greater than that calculated by the approximate equation. The present work indicates that the theoretical numbers should be uniformly about 30 per cent. larger than those calculated by Professor Rutherford.

PALMER PHYSICAL LABORATORY,
PRINCETON, NEW JERSEY.

THE VARIATION WITH THE TEMPERATURE OF THE THERMAL CONDUCTIVITY OF CAST IRON.

BY ELMER E. HALL.

SYNOPSIS.

Variation with Temperature of the Thermal Conductivity of Soft Gray Cast Iron, 195° to 542° C.—The sample used contained 3.5, 2.2 and 0.64 per cent. of C, Si and Mn respectively, and was cast into the form of a cylindrical shell 3 cm. thick, joined with a hemi-spherical bottom. The temperature differences between the liquids inside and outside the shell, which amounted to from 3° to 6° with an input of from 0.24 to 1.6 kw, were measured with thermo-couples silver-soldered in the ends of brass tubes. Since even though these tubes were pressed against the iron surfaces, the temperatures thus measured differed more or less from the actual temperatures of the surfaces, the absolute values found for the conductivity are too low; but the results indicate that the conductivity at 542° is between 2 and 3 times its value at 195° C.

IT was discovered in 1852 by J. D. Forbes (Atheneum, p. 102, 1852) that the thermal conductivity of iron was different at different temperatures. Investigations since that date have seemed to establish the fact that the conductivity of pure wrought iron decreases while that of cast iron increases with rise of temperature. This paper gives the results obtained for a specimen of soft cast iron as used in stove castings, the specimen being cast by the San Francisco Stove Works. Professor W. C. Blasdale of the chemistry department of the University of California has determined the silicon (Si) and manganese content to be 2.19 and 0.64 per cent. respectively. The carbon content was approximately 3.5 per cent.

The form of the specimen was that suggested by Mr. Carl Hering (Trans. Am. Electrochem. Soc., 18, p. 213, 1910), being a cylindrical shell with one end capped with a hemispherical shell. The dimensions of the casting were as follows: length of the circular cylindrical shell, 25.2 cm. inner diameter 6.0 cm., outer diameter 12.0 cm. The inner and outer diameters of the hemispherical cap were 6.0 and 12.0 cm. respectively. The casting was well made and after being cleaned in the lathe the thickness of the wall as measured at different points varied from 3.0 cm. by less than one per cent.

The specimen was immersed in a bath in a vessel of the same shape as the specimen. The temperature of this outer bath was subject to control as the outer vessel was provided with both a heating and a

cooling coil. The interior of the specimen was filled with an electrically heated bath. Heat losses at the open end of the cylinder were prevented by keeping the temperature and temperature gradient immediately over the specimen and baths closely the same as that of the baths themselves. This was done by auxiliary heating coils, thus constituting a modified guard ring scheme. The heating element in the bath inside the specimen consisted of a graphite rod $\frac{5}{16}$ of an inch in diameter, inside a $\frac{1}{2}$ inch iron pipe, contact at the bottom of the pipe between pipe and rod being secured by having a little molten lead in the cap of the iron pipe. Asbestos string wound every few inches along the graphite rod prevented warping of the rod and insured sufficient electrical insulation. The upper ends of both the rod and the pipe were joined to heavy copper leads. The measurement of the difference in potential between the proper points in the heater system, together with the current used, gave means of determining the energy input, the power factor for this type of conductor being unity. Alternating current from a variable voltage step down transformer was used.

The temperature of the walls of the specimen was measured with four pairs of copper-constantin thermocouples, placed at various depths. The thermocouples were calibrated, using the boiling points of water, naphthalene and sulphur, the cold junctures being kept at 20° C. The thermocouples were made from No. 28 wire and special care was given to their construction. A small bulge was made near the end of a thin walled brass tube, the tube being about 4 mm. in diameter. The wires for a thermocouple, after being well annealed and joined with silver solder, were insulated with pieces of fine hard glass tubing. The couples were then inserted in the brass tube and the juncture drawn through a small hole in the center of the bulge until the glass insulation was tight against the inner wall of the tube and the juncture was in the wall of the thin brass tube. The opening was then closed with silver solder and the protruding wires cut. The end of the brass tube was then closed with a layer of asbestos and a brass plug, the union being made tight with silver solder. When in place the center of the bulge in the brass tube, and hence the juncture of the thermocouple, was pressed against the surface of the specimen. Both baths were vigorously stirred and the thermocouples gave the same readings irrespective of their depths.

Assuming radial flow of heat, mathematical analysis readily gives for this form of specimen,

$$k = \frac{aw}{Jt};$$

where k is the thermal conductivity in gram calories per deg. per cm. per sec.; w is the electrical power in watts transformed into heat within the specimen; J is the mechanical equivalent of heat; t is the fall in temperature through the wall of the specimen; and a is a constant depending on the dimensions of the specimen. It can be shown that

$$a = \frac{e \, ln \frac{D}{d}}{\frac{\pi}{2} dDln \frac{D}{d} + 2\pi Le},$$

e denotes the wall thickness, D the outside and d the inside diameter, L the length of the cylindrical part, ln stands for the natural logarithm. Inserting the dimensions of the specimen as given above and combining a and J we have

$$k = 0.000897 \, wt.$$

For temperatures below 300° C. the baths were paraffin and above this temperature the baths were lead. The readings were made by O. R. Hull and O. S. Imhoff, working independently and about one year apart; each man making a complete new set up, including new thermocouples. It took from fifteen to thirty hours to obtain constant conditions. Readings were not accepted until conditions, as determined by the readings, had remained practically constant for at least one hour. Readings were then recorded every minute for twenty minutes and the mean taken. Since power line current was used there was a slight fluctuation in input. This fluctuation was cared for by taking most of the readings at night, and by extending the readings over a twenty-minute period, the instruments being carefully watched for the hour preceding. The results are given in the following table.

Amperes.	Volts.	Watts.	Inside Temp. C.	Outside Temp. C.	Difference t.	Mean Temp.	Conductivity k.	Thermal Ohms.	Observer.
80.....	3.00	240	197	194	3.0	195.5	0.0718	3.32	H.
81.25...	3.00	243.75	199	196.1	2.9	197.6	.0754	3.17	I.
120.....	3.50	420	287.2	283.3	3.9	285.3	.0965	2.47	H.
108.....	3.32	358.56	287	283.7	3.3	285.4	.0975	2.45	I.
120.....	3.50	420	296.8	293.1	3.7	298.6	.1018	2.35	H.
125.....	4.89	611.25	405.2	401.4	3.8	403.3	.1443	1.66	I.
128.....	5.00	640	426.6	422.9	3.7	424.8	.1552	1.54	I.
135.....	5.51	743.85	445.0	440.8	4.2	442.9	.1589	1.50	I.
165.....	6.99	1,153.35	506.5	501.1	5.4	503.8	.1916	1.25	I.
178.....	7.30	1,299.40	528.7	523.0	5.7	525.9	.2044	1.17	I.
200.....	7.91	1,582	545.2	538.6	6.6	541.9	.2050	1.16	I.

The method is open to the objection applicable to all cases where measuring the temperature of a surface is involved. What is doubtless measured in every such case is the temperature slightly away from the surface. Since the thermal resistance of the surface film of a substance is greater than for the substance itself, and since the thermal conductivity of lead is less than that of iron, it might be expected that this method would give results slightly low for any given temperature. However the variation of the conductivity with the temperature is believed to be well exemplified.

UNIVERSITY OF CALIFORNIA,
DEPARTMENT OF PHYSICS.

PROCEEDINGS

OF THE

AMERICAN PHYSICAL SOCIETY.

MINUTES OF THE CHICAGO MEETING, NOVEMBER 25 AND 26, 1921.

THE 111th regular meeting of the American Physical Society was held at the University of Chicago on November 25 and 26, 1921. President Lyman of the American Physical Society presided.

At a meeting of the Council held on November 26 sixty-three persons were elected to *Membership* and two were transferred from *Membership* to *Fellowship*, as follows: *Elected to Membership:* Hilda Begeman, Victor H. Benioff, Lester I. Bockstahler, Robert B. Brode, Detler V. Bronk, James W. Broxon, Walter A. Buchheim, R. R. Chappell, Chien Cha, Tobias O. Chew, H. T. Clifton, J. Fenton Daugherty, Ward F. Davidson, Elmer R. Drew, Arthur R. Duane Jesse Wm. DuMond, J. W. Ellis, Kenneth V. Glentzer, Philip F. Gottling, E. T. Hoch, Paul L. Hoover, R. J. Hopkins, Harold O. Holte, Haidee H. Hoover, B. A. Howlett, Roy J. Kennedy, Freda Kergor, Arthur D. Kinsman, Arthur L. Klein, V. O. Knudsen, Israel Koral, Harold R. Laird, Claude J. Lapp, Marcella Lindeman, Edward M. Little, Elsie J. McFarland, Robert C. Matlock, Edna L. Meacham, Yi-Ch'i Mei, Charles F. Mercer, L. G. Morell, Larrance Page, Wellington A. Parlin, Thomas J. Parmley, Donald MacLean Purdy, P. S. Olmstead, Carl A. Richmond, F. L. Robeson, Glenn F. Rouse, Harvey C. Roys, Arthur E. Ruark, C. Arthur Smith, John E. Smith, William O. Smith, William G. Spandon, Ralph B. Spence, W. W. Steffey, Elbridge Z. Stowell, Philip Subkow, L. W. Taylor, Irving Wolff, Raymond F. Yates, Charles T. Zahn; transferred to *Fellowship:* G. M. Moffit and John K. Robertson.

The following program of forty-four papers was presented, eight being read by title.

Molecular Models: Benzene. JARED KIRTLAND MORSE.

The Mobilities of Electrons in Pure N_2. LEONARD B. LOEB.

On the Pressure Increase in the Corona Discharge. JAKOB KUNZ.

The Vibration of Wires in the Corona. CHARLES S. FAZEL.

The Path of a Rigid Electron Moving in a Magnetic Field of Constant Strength Rotating with Constant Angular Velocity. E. O. HULBURT.

The Effect of Ageing on the Secondary Electron Emission from Copper Surfaces. L. E. MCALLISTER.

Carbon Dioxide Band Spectra in the Near Infra-red. E. F. BARKER.

Recent Determinations of the Susceptibilities of Oxygen and Nitric Oxide and the Magneton. E. C. FRITTS.

The Growth and Decay of Photo-Thermionic Currents from Oxide Coated Filaments. H. D. ARNOLD and HERBERT E. IVES.

The Absolute Sizes of Certain Monovalent and Bivalent Ions. WHEELER P. DAVEY.

On the Universal Distance of the Order of 10^{-8} centimeters, between the Centers of the Nearest Atoms in Solids. ALBERT C. CREHORE.

The Classification and the Prediction of Isotopes. WILLIAM D. HARKINS.

The Nature of Charcoal "Sorption." H. HORTON SHELDON.

The Scattering of Electrons by Nickel. C. DAVISSON and C. H. KUNSMAN.

Width of Spectral Lines of Helium as a Function of Pressure in the Source. LLOYD W. TAYLOR.

On the Vacuum Spark Spectrum of Silicon. R. A. SAWYER and R. F. PATON.

The Sparking Potential in Argon at Reduced Pressures. E. R. STOEKLE.

The Action of Light on a Photographic Film. JAY W. WOODROW.

The Instructional Value of Certain Types of Motion Pictures. HARVEY B. LEMON.

Sensibility of the Ear to Small Differences in Intensity and Frequency. V. O. KNUDSEN.

The Efficiency of Artificial Aids to Hearing. PAUL E. SABINE.

Doppler's Principle Illustrated by Ripple Waves. F. R. WATSON and W. B. WORSHAM.

Einstein's Relativity and Gravitation. JOHN MILLIS.

Some Aspects of the Theory of Relativity. A. C. LUNN,

Atomic Constants and Dimensional Invariants. A. C. LUNN.

Measurements of the Amount of Scattered Homogeneous X-Rays of Wavelength 0.712Å. per Gram of Carbon. C. W. HEWLETT.

The Spectrum of Secondary X-Rays. ARTHUR H. COMPTON.

Oscillations of Temperature of an Incandescent Filament, and the Specific Heat of Tungsten. K. K. SMITH and P. W. BIGLER.

Effect of Tension on Thermoelectromotive Forces by Magnetization. ALPHEUS W. SMITH.

Positive Ray Analysis of Lithium and Zinc. A. J. DEMPSTER.

A Convenient Contactor for Small Currents. FREDERICK J. SCHLINK.

The Dielectric Constant of Mica. J. R. WEEKS, JR.

A Photomicrographic Study of a Series of Drawn Tungsten Wires. L. P. SIEG.

A Simplified Method of Correcting for the Decrement of a Decremeter. R. R. RAMSEY.

A New Visual Null Method for Conductivity Determination. FABIAN M. KANNENSTINE and ESME E. ROSAIRE.

Phase Relations in Coupled Circuits. N. H. WILLIAMS.

The Change of Mobility of the Positive Ion with Age in Oxygen and Nitrogen. HENRY A. ERICKSON.

Spherical Aberration in Thin Lenses. T. TOWNSEND SMITH.

A Low Resistance Connection with a Revolving Shaft. A. P. CARMAN.

The Effect of Pressure and Gas Content on the Action of Vacuum Tube Detectors. H. A. BROWN and CHAS. T. KNIPP.

Some Remarks on Electromagnetic Induction. S. J. BARNETT.

The Existence of Small Ions of Very High Mobilities. OSWALD BLACKWOOD.

Effect of Lunar Gravity upon a Quartz Thread Balance. R. C. HARTSOUGH.

On the Electrical Properties of Illium. CHAS. T. KNIPP and J. L. HALL.

HENRY CREW,
Secretary, pro tem.

MOLECULAR MODELS: BENZENE.

BY JARED KIRTLAND MORSE.

IT has been found possible to construct a three-dimensional model for a molecule of benzene which is based on its chemical properties, by arranging the carbon nuclei at the corners of a regular octahedron and by placing the hydrogen nuclei along the axes of this geometrical form; three of the hydrogen nuclei being placed at a distance (y) and the remaining three nuclei at a distance (z) from their respective corners of the octahedron whose edge is denoted by (x).

Such a model has three distinctive axes given by the expressions: $2x\cos 45^\circ + 2y$; $2x\cos 45^\circ + 2z$; $2x\cos 45^\circ + y + z$.

It can be shown that the lengths of these axes also are given by the formulæ

$$\sqrt[3]{\frac{na^2\mu}{\rho c N}};\quad \sqrt[3]{\frac{n\mu}{ac N\rho}};\quad \sqrt[3]{\frac{n\mu c}{\rho a N}},$$

where n denotes the number of molecules common to the elementary space lattice, μ the molecular weight, a and c the crystallographic axial ratios, ρ the density, and N Avrogadro's number. Putting the vaules computed from these formulæ equal to our expressions in x, y, and z, we obtain the equations:

$$\begin{aligned} 2x\cos 45^\circ + 2y &= 7.983 \times 10^{-8}\text{ cm.}\\ 2x\cos 45^\circ + 2z &= 9.979 \times 10^{-8}\text{ cm.}\\ 2x\cos 45^\circ + y + z &= 8.981 \times 10^{-8}\text{ cm.} \end{aligned}$$

By taking $x = 2.514 \times 10^{-8}$ cm. as determined from Bragg's work on the structure of diamond and solving $x = 2.514 \times 10^{-8}$; $y = 2.214 \times 10^{-8}$; $z = 3.212 \times 10^{-8}$ cm.

By constructing models for naphthalene and anthracene and substituting these values in the expressions for their distinctive axes, axial ratios can be predicted which agree within the limits of experimental with the crystallographic measurements of these compounds.

UNIVERSITY OF CHICAGO,
November 7, 1921.

THE MOBILITIES OF ELECTRONS IN PURE N_2.

BY LEONARD B. LOEB.

IN the course of measurements of the constant of attachment of electrons to neutral molecules results were obtained indicating that the mobilities of the electrons in nitrogen were much higher than those given by previous observers. The mobilities of photoelectrons were accordingly determined in pure N_2 gas between pressures of 600 and 75 mm. using the Rutherford alternating current method. The alternating potentials were produced by the high-frequency oscillations of two audion oscillators acting in parallel and ranged from 7,000 cycles to 150,000 cycles per second.

The mobilities thus obtained were many times higher than those obtained by previous observers (*i.e.*, values of about 10,000 cm./sec. volt/cm. were found. They were furthermore not constant when reduced to a pressure of 760 mm. The values reduced to this pressure varied in a definite manner with changes in pressure, plate distance, and voltage between the plates. These variations may be summarized in the following equation for the mobility constant.

$$K = \frac{571{,}000}{21 + 760V/pd},$$

where V is the potential between the plates in volts, p is the pressure in mm. Hg, and d is the distance between the plates.

This unexpected variation of K with voltage explains certain peculiarities observed in the shapes of the mobility curves. A careful analysis of the method shows that the possible sources of error cannot account for the results.

The results are compared with the equation for electron mobility proposed by Townsend. This comparison leads one to conclude that the Townsend method of analysis must be abandoned or the following conclusions must be drawn. Either the energy lost by the electron at each impact with the nitrogen molecule is less the greater the energy of the electron, or the mean free path of the electron is some function of its energy. In any case, the mean free paths of the electrons in nitrogen gas must be about 3.9 times the mean free paths of electrons to be expected on the basis of simple kinetic theory, viz., $4\sqrt{2}$ the mean free path of gas molecules.

UNIVERSITY OF CHICAGO,
October 31, 1921.

ON THE PRESSURE INCREASE IN THE CORONA DISCHARGE.

BY JAKOB KUNZ.

IT is assumed that the electric momentum of the ions in the corona discharge is transferred to the gas molecules, which acquire a mechanical momentum, which makes itself felt as a pressure increase. The ratio of the mobilities of the ions of various gases is calculated and found to agree with the same ratios obtained by measurements in different processes of ionization. A

large amount of heavy ions is present in the corona discharge. The time required for the evolution of the corona pressure is calculated and found to be in agreement with experience. The phenomena of pressure increase in alternating current corona are also explained.

UNIVERSITY OF ILLINOIS,
November 6, 1921.

THE VIBRATION OF WIRES IN THE CORONA.

BY CHARLES S. FAZEL.

THE vibration of wires carrying a sufficiently high potential to show the corona has been reported by a number of observers. This effect takes place in both the direct and alternating current corona. In view of the close relation between the electric wind, the corona pressure, and this type of vibration, the conditions for its production have been studied. Thus far these studies have been confined to the case of an alternating potential between parallel wires.

It has been found that in order to get maximum vibration the natural frequency of the wire must be the same as that of the impressed potential. However it is necessary that the tension on the wire be small. That is the resonance amplitude is larger with smaller tension.

As the voltage is increased the amplitude increases very abruptly but soon reaches a constant value. This value is maintained as the voltage is increased until a critical voltage is reached where another sharp increase to a constant value is observed. The location of this critical voltage depends on the distance between the wires. The final value of the amplitude is maintained until the arc stage is reached.

The relation between the voltage and the amplitude may be explained on Kunz's theory of the corona pressure. In the first stage the vibration of the wire is due to the momentum of the high mobility carriers. When sufficient electric force is available to get the low mobility, heavy carriers across in the time between alternations, their effect is shown by the second stage of the curve.

UNIVERSITY OF MICHIGAN.

THE PATH OF A RIGID ELECTRON MOVING IN A MAGNETIC FIELD OF CONSTANT STRENGTH ROTATING WITH CONSTANT ANGULAR VELOCITY.

BY E. O. HULBURT.

A RIGID electron is assumed of mass m and charge e. The reactions on its motion due to finite size, radiation, and the variation of mass with velocity are neglected. The electron is subjected to a magnetic field H which rotates in the XZ plane. The X, Y and Z components of the magnetic field are, respectively, $H \cos \omega t$, o, and $H \sin \omega t$, where $\omega/2\pi$ is the frequency of rotation. Let x, y and z be the positional coördinates of the electron. When Newtonian notation and electromagnetic units are used, the equations of motion of the electron are

$$\frac{m}{e}\ddot{x} = -H\dot{y}\sin\omega t,$$

$$\frac{m}{e}\ddot{y} = H(\dot{x}\sin\omega t - \dot{z}\cos\omega t),$$

$$\frac{m}{e}\ddot{z} = H\dot{y}\cos\omega t.$$

These equations were solved and the constants determined for two sets of initial conditions. Given initially $t = 0$, $x = y = z = \dot{x} = \dot{y} = 0$ and $\dot{z} = W$, the path of the electron was found to be a wavy curve inside of a ring whose axis is parallel to the Y axis. Given initially $t = 0$, $x = y = z = \dot{x} = \dot{z} = 0$ and $\dot{y} = V$, the path of the electron was a rather complicated type of spiral winding in the general direction of the Y axis.

A special case occurs when ω is large. By means of high-frequency alternating current, such as is obtained in electron tube circuits, it is possible to produce magnetic fields which rotate with frequencies of the order of 10^6. When ω is large the positional coördinates of the electron in some cases become large, the velocities, however, remain in general small. Hence the magnetic field when rotating at high frequency does not impart a great velocity to the electron.

STATE UNIVERSITY OF IOWA,
November, 1921.

THE EFFECT OF AGEING ON THE SECONDARY ELECTRON EMISSION FROM COPPER SURFACES.

BY L. E. MCALLISTER.

SOME experiments on the secondary electron emission from copper surfaces were reported by Dr. I. G. Barber in the PHYSICAL REVIEW of March, 1921, and by Millikan and Barber in Proceedings of the National Academy of Science, Jan., 1921. In these reports they outline methods for obtaining measurements on the velocity of emission of secondary electrons from a copper surface and the number of secondaries emitted per primary for various velocities of impact. They also suggest a possible method for measuring the ionization potential of the surface considered. This method has been found to give consistent results to less than one volt.

Similar and modified observations on the same apparatus have been made at various times during the year following those reports. These observations show that the number of secondaries per primary as well as the ionization potential gradually increases as the surface is aged by heating in vacuo in which the residual gas is air. The number of secondaries per primary can be reduced to the original values by heating the surface in an atmosphere of hydrogen. This experiment can be done repeatedly with the same results, indicating that the copper surface gradually changes to a copper oxide surface

which can be reduced by heating in hydrogen. The copper surface was observed to be of a darker color only at the places where the secondaries were being emitted. Experiments are now in progress to test these effects on other metals.

UNIVERSITY OF CHICAGO.

CARBON DIOXIDE BAND SPECTRA IN THE NEAR INFRA-RED.

BY E. F. BARKER.

THE absorption regions of CO_2 at 2.7 μ and 4.3 μ have been reëxamined with the higher resolution afforded by a prism-grating spectrometer. The 2.7 μ region, heretofore considered to be a doublet, proves to be a pair of doublets, with centers at approximately 2.69 μ and 2.76 μ. The 4.3 μ band appears as a single doublet. Complete resolution of the band series has not been effected, but there is evidence of a "head" in each case on the side of shorter wave-lengths. The existence of this head for the 4.3 μ band is also indicated by a comparison with the emission spectrum from a bunsen flame.

From the doublet spacing an approximate value of the moment of inertia for the CO_2 molecule is obtained.

UNIVERSITY OF MICHIGAN.

RECENT DETERMINATIONS OF THE SUSCEPTIBILITIES OF OXYGEN AND NITRIC OXIDE AND THE MAGNETON.

BY E. C. FRITTS.

PAULI[1] has modified Langevin's equation for the magnetic moment of a gas per gram molecule at absolute zero. Instead of

$$\sigma_{m_0} = \sqrt{3RC_m},$$

he writes

$$\sigma_{m_0} = \sqrt{\frac{3RC_m}{\frac{1}{2}(n+1)(2n+1)}},$$

where n is a quantum number 1, 2, 3 $\cdots$. Pauli has also applied this theory to the values of the susceptibilities of oxygen and NO as determined by Piccard and found a fairly close agreement.

Piccard[2] and Soné[3] have recently redetermined the above susceptibilities. The values obtained are

Piccard,

$$\chi_{O_2} = 107.8 \times 10^{-6} \quad (20^\circ \text{ C.}),$$

$$\chi_{NO} = 48.6 \times 10^{-6} \quad (20^\circ \text{ C.}).$$

[1] Phys. Zeit., 21, p. 615, 1920.

[2] Jour. de Phys., Ser. VI, p. 97, 1920.

[3] Phil. Mag., 231, p. 305, 1920.

Soné,

$$\chi_{O_2} = 104.1 \times 10^{-6} \quad (20^\circ \text{ C.}).$$

The values, for oxygen 104.1×10^{-6}, and for NO 48.6×10^{-6}, give results in still closer agreement with Pauli's equation. The ratios of the theoretical and experimental values are, for O_2 1.019, and for NO 1.067, instead of 1 where for oxygen $n = 2$ and for NO $n = 1$.

We see that oxygen at least has very nearly a magneton of Bohr with the quantum number 2, or 2 magnetons. Experiments are in progress to redetermine the susceptibilities of paramagnetic and diamagnetic gases.

UNIVERSITY OF ILLINOIS,
October, 1921.

THE GROWTH AND DECAY OF PHOTO-THERMIONIC CURRENTS FROM OXIDE-COATED FILAMENTS.

BY H. D. ARNOLD AND HERBERT E. IVES.

AN investigation of the increase of thermionic current caused by illumination. It is found that the current increment due to red light grows and decays exactly as a similar increment due to increasing the temperature of the oxide coated filament. With blue light, on the contrary, the added thermionic current grows and decays at rates different from those due to heating, and at different rates depending on the temperature. At low filament temperatures the added current rises and falls very slowly; at high temperatures it rises and falls abruptly. These properties of the added current due to blue light are considered to differentiate it from a true photo-electric current which, as far as known, rises and falls instantaneously at all temperatures. It is concluded that previously recorded observations on changes in the magnitude of the added current with variation of filament temperature, do not necessarily imply a temperature coefficient of the true photo-electric effect.

RESEARCH LABORATORIES OF THE
AMERICAN TELEPHONE & TELEGRAPH COMPANY
AND WESTERN ELECTRIC COMPANY, INC.

THE ABSOLUTE SIZES OF CERTAIN MONOVALENT AND BIVALENT IONS.[1]

BY WHEELER P. DAVEY.

IN a preceding paper[2] attention was called to the fact that if the dimensions of crystals were used alone, to find the absolute sizes of ions, the solution was indeterminate, for there were $n - 1$ equations with which to solve for n unknowns. At that time a consideration of the diffraction patterns of KCl led to the assumption that $\overset{+}{K}$, $\overset{+}{Rb}$, and $\overset{+}{Cs}$ were equal in size respectively to

[1] Abstract of a paper to be presented at the Am. Phys. Soc., November, 1921.

[2] W. P. Davey, PHYS. REV., Aug., 1921.

$\bar{Cl}$, $\bar{Br}$ and $\bar{I}$, thus giving $n + 2$ equations for n unknowns. The concordant numerical results obtained by the use of these three additional, independent equations amply justified the assumption, at least to an accuracy of one per cent. At that time, values were reported for the "radii" of ions of the alkali metals and of the halogens. It is the purpose of the present paper to report the corresponding dimensions of $\overset{+}{Ag}$, $\overset{+}{Cu}$ and of certain bivalent ions.

Since the dimensions of bivalent metallic ions are most conveniently determined from the crystals of their oxides and sulphides, it was necessary to obtain as accurate a determination as possible of the "radius" of $\overline{\overline{O}}$. To this end, four routes were employed, namely (1) CsI–AgI–Ag_2O; (2) CsI–CuI–Cu_2O; (3) KCl–KF–CaF_2–CaO; (4) KCl–KF–BaF_2–BaO. The first two of these depend primarily upon the assumption that the radii of $\overset{+}{Cs}$ and $\overset{+}{I}$ are equal. The last two depend upon the assumption that the radii of $\overset{+}{K}$ and $\bar{Cl}$ are equal. The last two routes are longer than the first two, so that the cumulative effect of experimental errors in the data is greater. These last routes, therefore, should not be expected to give as concordant results as the first two routes. They should, however, at least serve as valuable checks upon the validity of the results, since they are arrived at by means of values which are quite independent of those used in the first two routes.

Routes 1 and 2.—The chloride, bromide, and iodide of silver were investigated. The first two were found to be simple cubes of ions of side 2.76 and 2.89 Å. respectively. Silver iodide is a diamond-cube of ions of side 6.53 Å., *i.e.*, the shortest distance between centers of $\overset{+}{Ag}$ and $\bar{I}$ is 2.83 Å. These structures are in agreement with those reported by Wilsey[1] and the dimensions agree with his to within one per cent. The chloride and bromide give "radii" for $\overset{+}{Ag}$ of 1.20 and 1.16 Å. respectively. The dimensions of the two crystals would not have to be in error by more than $\frac{2}{3}$ of one per cent. to account for this difference. The iodide gave a radius for $\overset{+}{Ag}$ of .85 Å. This discrepancy can not be accounted for on the basis of experimental error. CuCl, CuBr, and CuI crystals are all diamond-cubes of ions, with sides 2.32, 2.49 and 2.63 Å. respectively, giving "radii" for $\overset{+}{Cu}$ of .76, .76 and .65 Å. Here, as in the case of $\overset{+}{Ag}$ the values obtained from the chloride and bromide are in agreement with each other, but are larger than that obtained from the iodide. Either the silver and copper ions are of such a shape that they appear to have two dimensions (such as might be obtained by ascribing a "radius" to a tetrahedron), or they occur in two entirely different shapes, thus giving two different dimensions. The latter possibility was predicted by Langmuir[2] in the case of Ni and Pd atoms. If this possibility is granted in the case of Ni and Pd

[1] R. B. Wilsey, Phil. Mag., *42*, 262 (1921).
[2] I. Langmuir, Jour. Am. Chem. Soc., 1919.

atoms, it should also hold for not only $\overset{+}{Cu}$ and $\overset{+}{Ag}$, but also for $\overset{++}{Zn}$ and $\overset{++}{Cd}$ *ions*. It will be shown below that $\overset{++}{Cd}$ appears to have two sizes. So far, only one size has been found for $\overset{++}{Zn}$.

Ag_2O and Cu_2O were each found to consist of a body-centered cube of $\overline{\overline{O}}$ and a face-centered cube of the metal ion. These two cubes interpenetrate in the manner described by Bragg for Cu_2O (cuprite).[1] The sides of the cubes are 4.69 and 4.26 Å. respectively. The position of the $\overline{\overline{O}}$ in Ag_2O is identical with the position of the $\bar{I}$ in the iodides,—it is in the center of a tetrahedron of $\overset{+}{Ag}$. The difference in "radii" between $\bar{I}$ and $\overline{\overline{O}}$ may therefore be determined directly by the difference in the distances between $\overset{+}{Ag}$ and $\bar{I}$ and between $\overset{+}{Ag}$ and $\overline{\overline{O}}$, *i.e.*, $\bar{I} - \overline{\overline{O}} = 2.83 - 2.03 = .80$. Since the "radius" of $\bar{I}$ is 1.98Å. the "radius" of $\overline{\overline{O}}$ is 1.18 Å. A similar calculation, using Cu_2O and CuI gives $\bar{O} = 1.19$ Å.

Routes 3 and 4.—The structure of CaF_2 was shown by Bragg to be a modified diamond-cube. The side of this cube is 5.49 Å., so that the distance between centers of $\overset{++}{Ca}$ and $\bar{F}$ is 2.38 Å. Since the "radius" of $\bar{F}$ is 1.13 Å., the "radius" of Ca should be 1.25 Å. Now CaO is a simple cube of ions, of side 2.42 Å.[2] This gives a "radius" for O of 1.17 Å. BaF_2 has a structure like that of CaF_2. The side of the cube is 6.20 Å., giving a distance between centers of $\overset{++}{Ba}$ and $\bar{F}$ of 2.69 Å. This gives a "radius" for $\overset{++}{Ba}$ of 1.56 Å. Bragg[3] gives the distance between centers of $\overset{++}{Ba}$ and $\overline{\overline{O}}$ as 2.81 Å. This leaves the "radius" of $\overline{\overline{O}}$ as 1.25 Å. These two values of 1.17 and 1.25, obtained by routes 3 and 4 check very well with the values of 1.18 and 1.19 obtained by the more direct routes 1 and 2. The "radius" of $\overline{\overline{O}}$ will therefore be considered to be 1.19 Å.

The difference in the "radii" of $\overline{\overline{O}}$ and $\overline{\overline{S}}$ as shown by BaO and BaS is .39 Å., by ZnO and ZnS, .40 Å., by CaO and CaS, .40 Å. The "radius" of $\overline{\overline{S}}$ may therefore be taken as 1.59 Å. The following table gives the values for the "radii" of ions which have been determined since the report in the PHYSICAL REVIEW of Aug. 1921. Crystal data on SrO and BaO are from Bragg's published work. All other data are from this laboratory.

[1] W. H. and W. L. Bragg, X-Rays and Crystal Structure.
[2] W. P. Davey, PHYS. REV., May, 1920.
[3] W. L. Bragg, Phil. Mag., Aug., 1920.

Ion.	Crystal.	"Radius."
$\overset{--}{O}$	CaO — 1.17 BaO — 1.25 Cu_2O — 1.19 Ag_2O — 1.18	1.19 — Å.
$\overset{--}{S}$	CaS — 1.59 ZnS — 1.59 BaS — 1.58	1.59
$\overset{+}{Cu}_{(1)}$	Cu Cl — .76 Cu Br — .76	.76
$\overset{+}{Cu}_{(2)}$	CuI	.65
$\overset{+}{Ag}_{(1)}$	Ag Cl — 1.20 Ag Br — 1.16	1.18
$\overset{+}{Ag}_{(2)}$	AgI	.85
$\overset{+}{Tl}$	Tl Cl	1.77
$\overset{++}{Mg}$	MgO	.90
$\overset{++}{Ca}$	CaF_2	1.25
$\overset{++}{Sr}$	SrO — 1.44 SrF_2 — 1.40	1.42
$\overset{++}{Ba}$	BaF_2	1.56
$\overset{++}{Zn}$	ZnO	.76
$\overset{++}{Cd}_{(1)}$	CdO	1.11
$\overset{+}{Cd}_{(2)}$	CdS	.95
$\overset{++}{Ni}$	NiO	.88
$\overset{++}{Sn}$	SnS	.93
$\overset{++}{Pb}$	PbS	1.33

RESEARCH LABORATORY,
GENERAL ELECTRIC CO.,
SCHENECTADY, N. Y.,
November 2, 1921.

ON THE UNIVERSAL DISTANCE OF THE ORDER OF 10^{-8} CM. BETWEEN THE CENTERS OF THE NEAREST ATOMS IN SOLIDS.

BY ALBERT C. CREHORE.

BY using the model of the atom described in previous abstracts[1] it has been found that two such atoms may unite to form a diatomic molecule. The distance between the two atoms is of the order of 10^{-8} cm., and the common

[1] PHYS. REV., April, 1921, pp. 541, 544.

angle between the line joining them and their rotation axes is about 50° 11′. So far as the translational forces are concerned the surprising result is obtained that electrostatic forces alone are sufficient to produce this stable equilibrium, that is merely by the use of the inverse square law between infinitesimal elements of charge. To obtain this result, however, requires that the ratio of the major to the minor axes of the electrons shall be about three to one. This is also the shape assigned to the electrons on other grounds in the previous abstracts cited, and, hence, the two independent results support each other.

This result is, therefore, independent of the special form of electromagnetic theory employed, whether the Saha theory or that of Lorentz. It requires between 10,000 and 100,000 such atoms strung together to bridge the distance 10^{-8} cm. This means that there is plenty of room for the smallest dimension of the molecule to be of the order of 10^{-8}, 10^{-9}, 10^{-10}, 10^{-11} or even 10^{-12} cm., and it has been difficult to understand why 10^{-8} cm. is the order selected by practically all forms of atoms as the smallest dimension of its molecules approximately speaking. The above example, which is typical of all, attributes this particular value 10^{-8} cm. to the shape of the electron itself. Granting that this is the truth of the matter, the universal presence of electrons as parts of all atoms makes it reasonable that 10^{-8} cm. should be a universal order of distance.

The secret of obtaining any result by the use of electrostatic forces so far as translational forces are concerned is connected with the kind of atom used, in which the positive and the negative electrons are already in equilibrium because of their very close proximity to each other.

CLEVELAND, OHIO,
November 7, 1921.

THE CLASSIFICATION AND THE PREDICTION OF ISOTOPES.

BY WILLIAM D. HARKINS.

AN earlier paper in this REVIEW (*15*. 73–94 (1920)) pointed out the fact that nearly all known atoms contain an even number of negative nuclear electrons. Atom nuclei may be divided into four classes. Ninety per cent. of all known atoms belong to Class I., in which the number (P) of positive electrons and the number (N) of negative nuclear electrons are both even. In Class II. N is even and P is odd and in Class III. both are odd. Almost no atoms of Class IV. exist either on earth or in the meteorites. In this class N is odd and P is even. In 1915 Harkins and Wilson developed the following equation for the atomic weights of the atomic species:

$$P = 2(M + f),$$

in which P designates the atomic weight, M is the atomic number, and f varies in steps of $\frac{1}{2}$ from -1 to 27, but for complex nuclei only from 0 to 27. The value of f gives the number of cementing electrons for all atoms whose

atomic weight is divisible by 4. The values of $2f$ are more suited for use as the basis of a system of classification, since they include only every whole number from 0 to 57, if only complex nuclei are considered. The number $2f$ may be designated as the isotopic number (n). Atoms may be classified also according to the disintegration or aggregation series to which they belong. The paper will consider a nomenclature of the radioactive and other isotopes based upon these systems of classification.

The principles previously developed indicate that in general the number of isotopes of elements of even number is considerably greater than for elements of odd atomic number, particularly for elements whose atomic number is greater than thirty. The most abundant isotope and most of the other isotopes of an element of even atomic number, have atomic weights which are even numbers, while if the atomic number is odd the atomic weights of the isotopes are almost always odd. If the chemical atomic weight is known with a high degree of precision, most of the isotopes may be predicted by the use of these and other relations.

UNIVERSITY OF CHICAGO.

THE NATURE OF CHARCOAL "SORPTION."

BY H. HORTON SHELDON.

IT has been pointed out by Dr. J. W. McBain[1] that charcoal "sorption" of gases can be divided into two parts, adsorption on the surface and absorption into the interior. The adsorption he assumes to take place according to the theory suggested by Dr. Langmuir but the absorption he considers to be solid solution, and extends this to include the case of "sorption" of iodine from solutions of benzene, etc.[2]

Plotting the pressure-time curve for gases, or the concentration time-curve for solutions, there are evidently two distinct parts to the curve, separated by a bend. That this actually exists can be shown by plotting the logarithms of the numbers used, in which case the bend is such as to be unmistakable.

This undoubtedly means a dual action, the second beginning however only after the first is well on its way toward completion. Since solution should begin as soon as adsorption does, the bend is not accounted for and accordingly it is suggested that the second part is due to diffusion into the more inaccessible channels, which cannot be expected to take place to any extent until the easily accessible or directly exposed portions are saturated.

UNIVERSITY OF MICHIGAN.

THE SCATTERING OF ELECTRONS BY NICKEL.

BY C. DAVISSON AND C. H. KUNSMAN.

THE emission from a nickel target under bombardment by electrons has been found to contain a small fraction of electrons with speeds comparable

[1] Phil. Mag., 6, 18, 916, 1909.

[2] Trans. Faraday Soc., XIV., 3, 202, 1919.

to the speed of the incident electrons for bombarding potentials at least to 500 volts. No certain difference has been found between the speed of the fastest of these emitted electrons and the speed of the primaries.

A study of the number of these high speed electrons emitted per unit solid angle in various directions in a plane through the incident beam shows that the distribution for bombarding potentials at least to 500 volts is characterized by two maxima. One of these lies in a direction opposite to that of the motion of the incident electrons, and the other in a direction making an angle with this that depends for its value on the bombarding potential. The maximum in the direction of the beam is not directly observed but is inferred from the form of the distribution curves in the angular range from the lateral maximum to a direction 25 degrees from the incident beam. The angle between the principal and lateral maxima is about 70 degrees for a bombarding potential of 200 volts and is greater for both higher and lower potentials.

The distribution curves are apparently unrelated to the orientation of the target except as the position of the target limits the region into which electrons are free to emerge. It is inferred from this that the complete distribution of the high-speed electrons is represented by a figure of revolution about the incident beam.

It seems reasonable to suppose that these high-speed electrons emitted from the target are primary electrons that have suffered sharp deflections without appreciable loss of energy in encounters with single nickel atoms. It is unlikely that the field about the nickel atom is sufficiently strong to reverse the direction of motion of an electron approaching it with 500 volts speed. It is equally unlikely that the encounters involve only the incident electrons and the nuclei of the atoms, as there are difficulties in this case in accounting for the more moderate deflections. It appears, however, that all of the features of the distribution curves so far observed can be reasonably accounted for on the assumption that under favorable conditions an incident electron may pass in and out of the atom structure without appreciable loss of energy, and that its deflection within the atom is determined by the field of the nucleus as modified by the surrounding shells of electrons.

If the field in and about the atom is to be reckoned on the basis of the ordinary laws of electrostatics, then the field of an atom of the Lewis-Langmuir type will be more or less similar to the field of a concentrated positive charge surrounded by concentric spherical shells of uniformly distributed negative charge—that is, the field will be, on the whole, radial, and characterized by discontinuities or, at any rate, by sharp changes through the positions of the shells. It turns out that if electrons moving with equal speeds on parallel lines are projected into such a field the scattering to be expected will have, under appropriate conditions, features similar to those exhibited by the scattering from nickel. In particular, if the system consists of a positive nucleus and a single shell of equal and opposite charge it may be shown that the intensity of scattering in a direction making an angle Ψ with the incident beam will be given by

$$I_\Psi = k\left(\frac{2\beta - 1}{(2\beta - 1)^2(1 + \cos\Psi) + (1 - \cos\Psi)}\right)^2,$$

where

$$\beta = \frac{V\rho}{E},$$

V being the potential drop through which the bombarding electrons have acquired their speed.

ρ, the radius of the shell.

and

E, the nuclear charge.

$\Psi = 0$ is the direction back along the path of the incident electrons.

An examination of this expression shows that for all values of $\beta < 1$, I_Ψ has its maximum value in the direction $\Psi = 0$. This feature is a direct result of the limitation of the field of the nucleus and is not present when the field is unlimited as in the case of the scattering of alpha particles. In this case all appreciable deflections occur inside the innermost shell of electrons. For the system equivalent to a nucleus of eight electronic charge surrounded by a shell of eight electrons and of radius 5×10^{-9} cm. $\beta = 1$ corresponds to a bombarding potential of 229 volts, so that, for such a system there should be a maximum in the intensity of scattering in the direction $\Psi = 0$ for all lower values of this potential.

The main features of the distribution curves for nickel, including the lateral maximum of variable position, are to be expected if the nickel atom has its electrons arranged in two shells. Such an arrangement is incompatible with chemical and other data which require the 28 electrons of nickel to be arranged in either three or four shells. It is not to be expected, however, that the innermost shell of two electrons will contribute any prominent feature to the distribution of scattered electrons. It is also possible that when nickel is in the solid state the outer shell of electrons is more or less completely dispersed, as has recently been suggested by Broglie and Dauvillier. On the other hand, minor details due to other shells may be found when the distribution curves are studied with greater resolving power, and other features may appear in as yet unexplored ranges of bombarding potential.

RESEARCH LABORATORIES OF THE
AMERICAN TELEGRAPH AND TELEPHONE COMPANY,
AND THE WESTERN ELECTRIC COMPANY, INC.,
November 4, 1921.

WIDTH OF SPECTRAL LINES OF HELIUM AS A FUNCTION OF PRESSURE IN THE SOURCE.

BY LLOYD W. TAYLOR.

THE method of visibility-curve analysis is applied to a study of some of the more prominent lines in the visible spectrum of helium. Report is made on the width of the 5876 line as a function of pressure in the discharge tube.

Between pressures of 1 and 16 centimeters the half-width of this line is found to increase from 0.021 Å. at the lower to 0.041 Å. at the higher pressure, at a rate which is very nearly linear. This is in accordance with a law announced by Michelson in 1896.

The investigation is still under way for the purpose of measuring the width of other lines of the same gas and of extending the upper limit of pressure.

THE UNIVERSITY OF CHICAGO.

ON THE VACUUM SPARK SPECTRUM OF SILICON.

BY R. A. SAWYER AND R. F. PATON.

WAVE-LENGTH measurements on silicon have been published by Rowland, Lockyer, Exner and Haschek, Eder and Valenta, Crookes and one or two other observers. Inspection of their data shows that the various observers agree on but few lines. Even on these few lines discrepancies in wave-length occur.

Wave-lengths in the Visible Part of the Spectrum of Silicon.

Intensity.	Wave-length I.A.	Mean Wave-length by Other Observers.	Intensity.	Wave-length I.A.	Mean Wave-length by Other Observers.
1	4085.25	—	0	4673.27	—
3	4088.86	4088.86	2	4682.99	—
3	4116.16	4116.05	0	4709.03	—
3	4128.18	4128.00	3	4716.68	—
3	4131.05	4130.99	1	4733.35	—
1	4150.26	—	1	4800.37	—
0	4153.25	—	2	4813.21	4812
1	4190.96	4190.0	2	4819.54	4819
1	4198.25	4198.0	3	4828.81	4829
1	4212.64	—	0	4907.23	—
1	4215.58	—	0	4922.28	—
0	4254.42	—	0	4933.97	—
0	4257.66	—	3	5041.28	5043.2 ± 1.5
0	4259.21	—	4	5055.96	5058.0 ± 1.5
0	4262.29	—	0	5182.32	—
1	4267.19	—	0	5186.36	—
1	4277.91	—	0	5192.66	—
0	4314.26	—	1	5202.98	—
1	4328.31	—	0	5669.8	—
2	4338.54	—	0	5689.9	—
10	4552.52	4552.57 ± .25	2	5740.2	5740.4
8	4767.59	4767.65 ± .5	0	5868.4	—
7	4574.67	4574.64 ± .2	0	5889.7	—
1	4619.45	—	1	5957.8	5960.6 ± .8
2	4631.15	—	1	5979.4	5980.3 ± 1.5
1	4638.23	—	2	6347.9	6346.8
2	4654.07	—	1	6372.2	6370.1 ± .7
1	4665.54	—			

The difficulties which these observers have met have been largely experimental. Due to the rapid oxidization of silicon in the spark satisfactory spectra have been very difficult to obtain. It seemed to the writers that the vacuum spark, developed by R. A. Millikan and one of the writers, should overcome this difficulty. For in the vacuum spark we have a means of producing a high voltage spark of great energy and with no possibility of oxidization.

A brass box was built which could be evacuated to an extremely low pressure by mercury vapor pumps. In this box silicon electrodes were mounted and the vacuum spark produced somewhat after the manner described by one of us (Astro. J., II., 286, 1920). Through a window in the box the spectrum of these sparks was photographed with a prism spectrograph. An iron arc comparison was used to determine the wave-lengths. The following table contains the wave-lengths in these spectra which are probably due to silicon. The wave-lengths due to impurities, which are chiefly iron, aluminum and calcium have been eliminated. It is believed that these wave-lengths are accurate in the range from 4100–5202 to one tenth of an Ångstrom or better, in the range from 5600–6400 to about three tenths of an Ångstrom.

Among these lines several groups of pairs of constant frequency difference have been noticed. The three most numerous groups of such pairs are included in the following table.

Pairs of Constant Frequency Difference in the Silicon Spectrum.

Int.	Wave-length	Frequency.	*dn.*	Int.	Wave-length.	Frequency	*dn.*	Int.	Wave-length.	Frequency	*dn.*
0	4907.23	20378.1	62.3	3	4128.18	24224.3	17.4	8	4567.59	21893.4	33.9
0	4922.28	20315.8		3	4131.05	24206.9		7	4574.67	21869.5	
0	5186.36	19281.4	61.6	1	4150.26	24094.9	17.4	2	4631.15	21592.9	33.0
1	5202.98	19219.8		1	4153.25	24077.5		1	4638.23	21559.9	
0	5669.8	17637.3	62.3	1	4212.64	23738.1	16.6	1	4665.54	21433.8	35.5
0	5689.7	17575.0		1	4215.58	23721.5		0	4673.27	21398.3	
0	5868.4	17040.4	61.6	0	4254.42	23505.0	17.9	0	4709.03	21235.8	34.4
0	5889.7	16978.8		0	4257.66	23487.1		3	4716.68	21201.4	
1	5957.8	16784.7	60.6	0	4259.21	23478.5	16.9				
1	5979.4	16724.1		0	4262.29	23461.6					
2	6347.9	15753.2	60.0								
2	6372.2	15693.2									

UNIVERSITY OF MICHIGAN.

THE SPARKING POTENTIAL IN ARGON AT REDUCED PRESSURES.

BY E. R. STOEKLE.

IN the course of some experiments with an arc between calcium electrodes in a pressure of 40 mm. of argon, it was found that the potential required to start an arc decreased to unexpectedly low values after the arc had been allowed to run for some time. For example, such a discharge tube filled with argon purified in an auxiliary calcium arc discharge, would require a starting potential of 300 volts shortly after being sealed from the line, but after being run at 3 amperes for about an hour, and then being allowed to cool, it restarted at only 108 volts. After running for several hours at this current, the arc could be cooled and restarted at a potential of only 90 volts. Even after standing cold for 15 hours the arc could be restarted at 120 volts. These values of the potential required to start a discharge in argon are far below the minimum sparking potential of 240 volts given for argon by Townsend.[1]

The most probable explanation of these low sparking potentials lies in the progressive purification of the argon by the calcium vapor formed in the arc discharge. There is, however, a probability that some slow chemical action between the calcium electrode and a trace of oxygen or other gas might cause the emission of electrons after the manner described by Haber and Just, and thus facilitate the starting of a discharge. In order to avoid such an effect, the sparking potential between brass electrodes in argon purified by a calcium discharge was studied.

The apparatus consisted of a discharge tube containing two circular brass electrodes of 35.5 mm. diameter, whose opposing faces were spherical surfaces of 10 cm. radii of curvature, and distant 3.20 mm. at their nearest points.

Two calcium electrodes were mounted in the same tube for the purpose of purifying the argon. The tube was connected to a mercury vapor pump and a supply of argon, and could be shut off from both lines by means of a mercury valve. After being thus shut off the pressure in the tube could be varied over a range of about 50 per cent. by means of an attached bulb, whose volume could be changed by adjusting the level of the mercury within it. A McLeod gauge reading up to 2.5 mm. pressure and a manometer for reading the higher pressures were attached to the tube.

In order to get rid of adsorbed gases in the apparatus, it was baked at 360° C. for three hours and the electrodes were heated by passing a discharge between them in argon, which was pumped out while the discharge was going on. Argon which had been purified by exposing it to a calcium arc discharge for a period of 10 hours and dried by passing it through a trap surrounded by carbon dioxide snow was then admitted to the apparatus. The calcium arc in the discharge tube itself served for the final purification, and this was performed after the tube had been shut from the line.

The sparking potential was observed by slowly raising the voltage between the electrodes by increasing the field excitation of a 500-volt generator. A

[1] Electricity in Gases (1915), p. 329.

resistance of 3,000 ohms was placed in series with the electrode gap, in order to limit the current and as soon as the discharge passed the circuit was opened to prevent unnecessary heating of the electrodes, which might cause the evolution of electrode gases. For each observation three readings were taken, about four minutes apart, and in general these agreed to within 3 per cent. All observations were taken in rather dim diffused daylight and no special means for initiating ionization was provided.

A minimum sparking potential of 176 v. for this relatively impure argon was found to occur at a value of $p \times d = 8$, when p is the pressure in millimeters of mercury and d is the distance between the electrodes in millimeters. For the argon purified by the calcium arc in the discharge vessel a minimum sparking potential of 137 volts occurred at $p \times d = 7$.

The values of sparking potential obtained in this apparatus, although lower than any known to the writer, may not be as low as could be obtained in still purer argon. The slightest trace of impurity, such as an air bubble liberated from the mercury in the gauges or in the mercury valve would produce a marked change in sparking potential with no observable change in the pressure. A series of such bubbles, which were allowed to enter the apparatus, changed the pressure about 1 per cent., but changed the sparking potential by 7.5 per cent. It is, therefore, thought that by devising special means for measuring and varying the pressure of the argon without introducing impurities a lower minimum sparking potential than the observed 137 volts may be found to exist.

PHYSICAL LABORATORY,
THE CUTLER-HAMMER MFG. CO.

"THE ACTION OF LIGHT ON A PHOTOGRAPHIC FILM."

BY JAY W. WOODROW.

IT is a well-known fact that there is a remarkable similarity between the photoelectric and photographic properties of the silver halides. This has suggested to several writers (cf. Allen's "Photoelectricity," Chap. XIV.) the possibility of explaining the action of light on the photographic film as due to some sort of photoelectric action.

Now it has been shown that when plane-polarized light is incident upon a photoelectrically sensitive surface, more electrons are emitted when the electric vibration in the incident light is normal to the surface than when it is parallel to it. Consequently a very narrow line if photographed through a Nicol's prism should appear sharper when the direction of the electric vibration is parallel to the line than when at right angles to it. This was tried experimentally and found to be the case.

The source of light consisted of a very carefully ruled set of rectangular lines on a plane white background. Between this source and the camera lens was a high-grade Nicol's prism. The lens was a good anastigmatic lens, and fine-grained, contrast photographic plates were used.

Several photographs were taken with the Nicol so oriented as to make the

electric vibration parallel to the vertical lines and several with it parallel to the horizontal lines. In every case the lines parallel to the electric vector were the sharper. The direct image on the ground-glass of the camera was also examined with a magnifying glass but no difference could be observed between the two sets of lines.

These experiments seem to indicate the possibility of explaining the effect on the assumption of some photoelectric action. The experiments are being continued in a slightly different manner with the object of finding some more direct evidence of the effect.

IOWA STATE COLLEGE,
AMES, IOWA.

THE INSTRUCTIONAL VALUE OF CERTAIN TYPES OF MOTION PICTURES.

BY HARVEY B. LEMON.

THE motion picture possesses certain obvious advantages over the spoken lecture in technical instruction. By means of animated drawings certain types of small and rather complex mechanisms may be made clearer than by any other means. Experiments performed by means of photography on the screen never fail to function and may be repeated indefinitely. Motions much too rapid for the eye to follow may be slowed down and analyzed. These facts are universally recognized.

A direct comparison has been made at this laboratory of the relative effectiveness of the spoken demonstration lecture and the presentation of the same material by means of films. Classical experiments in electricity and magnetism were set up and photographed. The films were assembled with suitable explanatory titles and drawings and projected before a large class. The class was then given an examination covering the material presented. Another class received the lecture in the conventional fashion with the experiments themselves presented on the table. They were given the same examination as the others. The classes were interchanged. Other material was presented to both, but conditions were now reversed and those who formerly saw experiments now saw pictures of them, and vice versa. Each group was checked by examination. Examinations were graded by four different men all familiar with, and teaching in, the fields covered. Sufficient numbers of students were involved to ensure statistical results.

The final results gave confidence in the effectiveness of the film. Grades obtained from the motion picture presentation ran about 67 per cent.—those from the spoken lectures about 72 per cent. Other facts made this difference less significant.

The film was unsupported by any comment either before, during or after the showing. It occupied 15 to 20 minutes time: the spoken lecture, 60 minutes. The experiments themselves required two to three hours of labor in the preparation. The film, once obtained, required none.

It must be borne in mind that the above described work makes comparison

between films and but one of many types of instruction,—the demonstration lecture. Comparisons of films with laboratory methods, recitations, or problem solving types of instruction which are the *most important* teaching methods in science, would be obviously absurd.

UNIVERSITY OF CHICAGO,
November 9, 1921.

SENSIBILITY OF THE EAR TO SMALL DIFFERENCES IN INTENSITY AND FREQUENCY.

BY V. O. KNUDSEN.

A TELEPHONE receiver energized by a current from a vacuum tube oscillator is used as a source of sound for determining the sensibility of the ear to small differences of loudness and pitch. Tones varying in frequency from 30 d.v. to 20,000 d.v. are produced by the oscillator used in these experiments. By means of a divided resistance circuit the intensities of the tones can be varied by any desirable and measurable intervals from the threshold values up to very high values.

Some auxiliary experiments showed that the acoustical energy developed by the receiver diaphragm is a linear function of the electrical energy which actuates it. The electrical energy is therefore a convenient measure of the relative acoustical energy at any fixed frequency.

Data that have been taken thus far on a limited number of ears show that the sensibility of the ear to small differences in intensity, measured by the ratio of the smallest perceptible increment in energy to the whole energy, $\Delta E/E$, is —.

1. Dependent upon the intensity. The ratio $\Delta E/E$ decreases as the intensity increases. For a wide range of moderate and high intensities the sensibility is nearly constant. Its value for ordinary frequencies is roughly 0.10.

2. Nearly independent of the frequency between 100 d.v. and 4,000 d.v.

3. Nearly the same for all normal ears.

The sensibility of the ear to small differences in frequency measured by the ratio of the smallest perceptible increment to the whole, is —

1. Dependent upon the intensity. The law of variation with intensity closely resembles the law of variation of sensibility to small intensity differences.

2. Dependent upon the frequency. The sensibility ratio decreases from about 0.01 at 50 d.v. to about 0.002 at 1,000 d.v. For higher frequencies the ratio increases.

3. Only approximately the same for different ears.

UNIVERSITY OF CHICAGO.

THE EFFICIENCY OF ARTIFICIAL AIDS TO HEARING.

BY PAUL E. SABINE.

MEASUREMENTS were made to determine the amplification of sound by eleven different instruments commonly employed for the aid of the deaf. The measurements were made by timing the duration of sound, after the source of sound had ceased in a sound chamber, audible to a deaf person, with and without the instrument held to the ear. From the difference of time with and without the instrument and the known rate of decrease of intensity as the sound dies away in the room, the ratio of the intensities at the ear of the observer under the two conditions was computed by the equation

$$\log_e \frac{I_1}{I_2} = A(t_1 - t_2).$$

A being defined by the equation

$$\frac{dI}{dt} = -AI.$$

The experiments covered the range of pitch from 128 to 4096 d.v.

The amplifications produced by different instruments of the trumpet type were found to follow order of size of these instruments. The effect of the natural frequencies of the air columns enclosed by the trumpets were shown by increased amplifications for these frequencies. Instruments in which the vibrations of diaphragms held in contact with the teeth are supposed to be conducted to the auditory nerve by the bones of the skull were found to produce positive, though small amplifications. Telephonic devices showed relatively large amplifications for tones in the neighborhood of the natural frequencies of the diaphragms of the transmitter and receiver.

By comparison with the duration of sound audible to normal ears, the sensitivity of the ears of the deaf observer was determined in terms of norma sensitivity. The ratio of sensitivities so determined was of the order of 10^5 in the middle register. The maximum amplification produced by any of the trumpets was approximately $10^{1.3}$, while that for the telephone at the natural frequency of the receiver was $10^{2.5}$. The inadequacy of any of the instruments tested in the relief of cases of extreme deafness is thus shown.

WALLACE CLEMENT SABINE LABORATORY,
RIVERBANK, GENEVA, ILL.

DOPPLER'S PRINCIPLE ILLUSTRATED BY RIPPLE WAVES.

BY F. R. WATSON AND W. B. WORSHAM.

THE Doppler effect was observed when a source of ripple waves on water was made to move. The waves were generated by a jet of air directed against the surface of the water. For some cases, the stream of air was made to come in periodic puffs and the resulting waves were observed by means of a stroboscopic device so that they appeared to move slowly.[1]

[1] "A Study of Ripple Wave Motion," PHYS. REV., Vol. 7, pp. 226–228, 1916.

When the velocity of the source was less than the velocity of propagation of the waves, the waves were crowded together in front of the moving source thus giving an increase in the frequency, whereas behind the source, the waves were spread out corresponding to a fall in pitch. If the source was moved more rapidly than the waves, an overlapping resulted so that a tangent drawn to the contiguous crests gave a resultant similar to the wave set up by a bullet in flight.

Photographs were taken of a number of type cases with (1) the velocity of the source less than the wave velocity, (2) the velocity of the source greater than the waves, (3) the velocity of the source approximately equal to that of the waves, (4) various intermediate conditions.

Since these waves appear to move slowly, data may be obtained with comparative ease and thus yield information that will assist in explaining the phenomena of bullets in flight as well as other examples of Doppler's principle.

By photographing a scale with the waves, the wave-length may be found, so that, if the frequency of the puffs of air is known, the velocity of the source v may be calculated. By measuring the angle θ, between the median line and the wave front, the velocity V of the waves may be found according to the formula

$$V/v = \text{Sin } \theta.$$

UNIVERSITY OF ILLINOIS,
October, 1921.

EINSTEIN'S RELATIVITY AND GRAVITATION.

BY JOHN MILLIS.

NOTE is made of certain errors and misapprehensions found in publications relating to the relativity theories as indicated by the recently published book "Einstein's Theories of Relativity and Gravitation" by J. Malcolm Bird, associate editor, Scientific American. Considerable lack of clearness is found as to the real purpose and significance of the famous Michelson-Morley experiment. This, in a few words, was undertaken to test the relative movement of the apparatus used and the supposed medium which transmits light, the ether. No such relative movement has ever been detected either by this or by a number of other similar tests that have been carried out. The Lorentz-Fitzgerald explanation of this failure which is that the dimensions of all matter are affected by motions relative to the ether and that therefore no such relative movement can ever be detected by man, is not only highly improbable but is fallacious in the assumption that an ether could exist without its being possible to detect its presence by similar tests. It is shown that if an ether does exist and that if it affects matter as assumed, an apparatus could be constructed that would reverse this effect and therefore disclose it.

Some writers appear to assume that there is some relation between the so-called Lorentz-Fitzgerald effect in connection with the ether and the discrepancies that arise in certain measurements because of the time required to

convey intelligence from sensible distances. The velocity of light appears in both, but there is no real connection between them; the first is a mere speculation while the second is a reality.

It is demonstrated that there cannot be any superior limit to possible relative velocities; in other words, that the velocity of light is not such a limit, as has been assumed. The assumption that there can be a change of mass with change of velocity is also fallacious. Since all velocity is relative and a body may have an indefinite number of velocities at the same time, this assumption of a relation between mass and velocity would require that a body could have an indefinite number of masses simultaneously. Energy has been regarded as something definite or fixed, but a body may have an indefinite number of energies at the same time, depending on relative velocity.

There can be no special significance in the velocity of light as such as a fundamental physical principle. Such an assumption would be attaching to one of the sense organs of human beings who have had a comparatively recent career in the universe, an importance in connection with a general physical theory that facts do not warrant.

It is shown that certain ideas connected with centrifugal force in a relative sense are erroneous and it is also pointed out that the celebrated Foucault pendulum experiment and the behavior of the gyroscope do not establish the persistence of motion of a body "in space." These only show a tendency to preserve motion or position respecting the axis of the earth. Reference is made to the "Shadow-bands" which have been observed during a total eclipse near the edge of the moon's shadow as it passes over the earth and it is suggested that there may be some relation between the cause of these bands, whatever it is, and the displacement of stars observed during a total eclipse which has been regarded as confirming the Einstein theories.

The non-existence of any universal medium like ether is more comprehensible and consistent with the general structure of nature than would be such a medium as a demonstrated fact—this, notwithstanding the difficulty of understanding how gravitation and other so-called forces can be transmitted without any medium.

542 RUSH ST., CHICAGO, ILL.

SOME ASPECTS OF THE THEORY OF RELATIVITY.

BY A. C. LUNN.

THE Einstein theory may be considered as based on a combined differential geometry of space and time measurements but amplified into a comprehensive physical theory by the addition of various notions and postulates consistently interpretable in connection with the geometry but at least not known to be definable or deducible from it. Since particular contacts with experiment are concerned with these additional assumptions as well as with the main geometric basis it is conceivable that adaptation to results of observation may require,

and be attainable by, changes in some of these without departure from the general program.

This paper surveys the geometric materials available for physical interpretation, the extent to which physical theory has so far been absorbed into that interpretation or superposed upon it. At several points it appears that there is some flexibility of choice possible in certain of these auxiliary postulates, in particular as concerned with the relation of optical and mechanical phenomena within material bodies, the phenomena of rotation, and the meaning of an electromagnetic field.

UNIVERSITY OF CHICAGO.

ATOMIC CONSTANTS AND DIMENSIONAL INVARIANTS.

BY A. C. LUNN.

IT has been recognized for some time that the number of universal physical quantities revealed by experiment, but not yet utilized for the practical reduction of the system of arbitrary units, is more than sufficient to complete that reduction so as to give for every kind of measurement a natural unit. Since in most cases the measurements are not yet accurate enough for putting this reduction into effect it is convenient to retain consideration of those quantities as having dimensions corresponding to the scheme of units antecedent to such reduction. The redundancy means then that the excess quantities should be expressible in terms of the others, and several relations of this kind have been proposed. Equivalently, there must exist a number of dimensional invariants corresponding to this excess. On the one hand the recomputation of a suitable list of such invariants gives an impartial scheme for introducing improved values from measurement, and on the other a test of the scope of theory in a certain sense is found in the number of invariants whose values as deduced accord with experiment.

As illustration this paper lists seven quantities which can be considered as dimensioned in the familiar three-unit scheme and hence must have a fundamental system of four invariants, to which may be added the mass ratios of hydrogen and helium atoms to electron. The theories of Planck, Bohr, and Lewis and Adams in effect assign numerical values to three of these, and in this paper are shown certain tentative values for others enough to complete the list, so accurate in terms of present data as to suggest the possibility of deduction from theory, and such as to give in particular simple formulas for the action constant and constant of gravitation.

UNIVERSITY OF CHICAGO.

MEASUREMENTS OF THE AMOUNT OF SCATTERED HOMOGENEOUS X-RAYS OF WAVE-LENGTH 0.712 Å. PER GRAM OF CARBON.

BY C. W. HEWLETT.

A NARROW beam of x-rays from a molybdenum Coolidge tube excited at 30 k.v. was first passed through a zirconium filter and then allowed to fall on

the scattering material. The radiation transmitted by the filter under this condition was nearly homogeneous, being almost entirely the α_1 radiation of the K series of molybdenum.

The scattering material was contained in a cylindrical capsule 0.47 cm. in diameter and was mounted on the axis of an x-ray spectrometer in such a way that it could be continuously rotated during the scattering measurements. The scattered radiation was received by an ionization chamber which was mounted to rotate about the spectrometer axis and about 36 cm. from the scattering material. The ionization current was measured by a quadrant electrometer. The width of the primary beam of x-rays was slightly greater than that of the capsule of scattering material, and its height was 2.40 cm.

The scattering of powdered artificial graphite, liquid mesitylene and diamond chips was measured between 2° and 158° from the incident beam. The amount of scattering material for graphite and mesitylene was about 0.35 gm., and for diamond about 0.79 gm.

The intensity of the incident beam and that of the scattered radiation was measured in the same units. The total absorption coefficient, and the total amount of radiation taken from the primary beam by the scattering material, was measured for graphite and mesitylene. The total scattered radiation was then calculated as a fraction of the total radiation taken from the primary beam, making an estimated allowance for the scattering in the 0.50 unit solid angle inaccessible to the ionization chamber, and for the absorption of the scattered radiation within the scattering material. It was assumed that the true mass absorption coefficient of diamond was the same as that determined for graphite and mesitylene and the mass scattering coefficients of all three were calculated with the following results:

Substance.	Density	True Mass Abs. Coeff.	Mass Scattering Coefficient.
Mesitylene.....	.863	.351	.184
Graphite.....	1.48	.351	.198
Diamond.....	3.51	.351	.234

The above results are probably not in error by as much as 10 per cent.

Thomson's theory of scattering gives for carbon a mass scattering coefficient of .200. This is based on the assumptions (*a*) that the electrons are small compared to the wave-length of the primary beam, and (*b*) that they scatter independently. This latter condition is very probably not satisfied in the scattering by carbon of wave-length 0.712 Å. The increase in the scattering coefficient with increasing density shown in the accompanying table is very probably due to the fact that as the atoms get closer together the electrons under the influence of the primary radiation vibrate more nearly in phase and consequently emit more scattered radiation.

The distribution of the scattering for graphite and diamond shows the maxima characteristic of the crystal structures of these materials. The actual

amount of scattered radiation in the lines is however only a small per cent. of the total scattered radiation, a large part of it lying in between the maxima. Theory predicts a large intensity of scattering at very small angles from the primary beam, but these experiments show that the scattering approaches zero at these small angles. Determinations of the absorption coefficient in aluminum of the scattered radiation at fourteen angles about equally distributed in the region of investigation failed to show any difference in quality of the scattered and primary radiation.

STATE UNIVERSITY OF IOWA,
IOWA CITY, IOWA.

THE SPECTRUM OF SECONDARY X-RAYS.

BY ARTHUR H. COMPTON.

AN examination of the secondary rays excited in different materials when x-rays rendered nearly homogeneous by filtering were employed, showed that the secondary radiation was of a softer type than the primary rays which struck the radiator.[1] More recent experiments have shown that this phenomenon is not confined to heterogeneous x-rays, but occurs also when the rays incident upon the radiator have been reflected from a crystal.[2] The most obvious interpretation of these results was that in addition to scattered radiation there appeared in the secondary rays a type of fluorescent radiation, whose wave-length was nearly independent of the substance used as radiator, depending only upon the wave-length of the incident rays and the angle at which the secondary rays were examined.

In order to obtain more definite information with regard to the characteristics of the secondary x-radiation, a study has been made of the spectrum of the secondary rays excited in various substances by the x-rays from a Coolidge tube having a molybdenum target. A small piece of radiating material, such as celluloid or aluminium, placed in front of the first slit of the spectrometer, was illuminated by incident x-rays at approximately 90° with the secondary beam under investigation. The spectrum was studied by means of a calcite crystal grating, using both the ionization and photographic methods.

The spectra obtained show lines identical in wave-length with the primary K lines from molybdenum, thus proving that a part of the secondary radiation is truly scattered and unchanged in wave-length. In addition to these lines, a general radiation is observed which is more prominent in the secondary than in the primary beam. When the x-rays incident upon the radiator were unfiltered, the general secondary radiation had a broad intensity maximum at a wave-length slightly under 1 Å. U. On introducing a zirconium filter between the x-ray tube and the radiator, thus giving a primary beam consisting principally of the $K\alpha$ line from molybdenum together with some fluorescent K rays from zirconium, a much sharper maximum in the secondary fluorescent

[1] PHYS. REV., 18, 96 (1921).
[2] Nature, Nov. 17, 1921.

radiation was observed. This result has been verified by means of photographic spectra, which show a maximum of the general radiation at about 0.95 Å.U., which is about 35 per cent. greater than the wave-length of the exciting ray.

The energy in this general radiation is roughly 30 per cent. as great as the energy of the scattered K rays. Previous experiments have shown that when shorter wave-lengths are employed, the energy in the fluorescent rays may be even more prominent than the truly scattered rays. If we suppose that the incident x-ray beam ejects electrons moving forward with a kinetic energy hC/λ, where λ is the wave-length of the exciting ray, and if the ejected electron is oscillating at such a frequency that as observed in the direction of motion the wave-length is λ, on account of the Doppler effect the wave-length of the radiation at right angles with the primary beam will be very close to that of the fluorescent rays observed in these experiments.

WASHINGTON UNIVERSITY,
SAINT LOUIS.

OSCILLATIONS OF TEMPERATURE OF AN INCANDESCENT FILAMENT, AND THE SPECIFIC HEAT OF TUNGSTEN.

BY K. K. SMITH AND P. W. BIGLER.

THE primary object of this experiment was to test the practicability of using thermionic currents to record rapid changes in the temperature of a filament. By means of a double high-frequency oscillograph we have obtained continuous photographic records showing simultaneously the cyclic variations in thermionic emission from an incandescent tungsten filament in vacuo, and the variations in the alternating voltage across the filament. The thermionic current is a direct current on which are superposed oscillations of twice the supply frequency, which is 60 cycles per second. The constant potential difference, 220 volts, between the filament and the cylindrical anode was more than sufficient to secure saturation, and consequently variations in the thermionic current were produced wholly by changes in temperature. The thermionic current was returned through one strip of the oscillograph to the middle of a high resistance, and thence to the two ends of the filament so that the disturbing effect of the thermionic current was negligibly small. The other strip of the oscillograph was in series with a voltmeter, and this strip and the voltmeter formed a second shunt across the filament.

From observations on the change in the mean thermionic current resulting from a known change in the mean temperature, the measured variations on the plates have been translated into oscillations of temperature above and below the mean value. The lag of temperature behind the power has been found on the assumption that the thermionic emission is in phase with the temperature.

The theoretical relation between the oscillation in temperature and the heat capacity of the filament was deduced by Corbino[1]

[1] Phys. Zeitschr., XI., pp. 413–7, 1910.

Writing c = mean heat capacity of the wire in joules per degree,
$e_0 \sin \omega t$ = voltage between the ends of the filament,
T = instantaneous temperature,
$f(T)$ = total rate of loss of energy from the wire,
a = temperature coefficient of resistance,
r_m = resistance at mean temperature T_m,
θ = variation in temperature from T_m.

he has, from the energy principle,

$$c\frac{dT}{dt} + f(T) = \frac{e_0^2 \sin^2 \omega t}{r_m(1 + a\theta)}.$$

When θ is small in comparison with T_m, and Q is written in place of $a \cdot f(T_m) + df(T)/dT$, the differential equation reduces to

$$c\frac{d\theta}{dt} + Q \cdot \theta = -f(T_m) \cos 2\omega t.$$

The solution of this equation can be expressed in the form

$$\theta = \Theta \cdot \cos(2\omega t - \phi),$$

where Θ = the amplitude of the oscillation of temperature $= [-f(T_m) \cos \phi]/Q$, and $\tan \phi = 2c\omega/Q$.

Eliminating Q between the last two equations, and replacing $f(T_m)$ by W, the mean power spent in the wire, Corbino expressed the heat capacity in the form $c = -(W \sin \phi)/(2\omega\Theta)$.

The mean temperature of the filament was calculated from Langmuir's data on the volt-ampere characteristics of tungsten.[1] The filament, 0.004 cm. in diameter and 14.25 cm. long, was mounted along the axis of a pyrex tube 2.5 cm. in diameter, which contained a concentric cylinder of copper gauze 2.28 cm. in diameter. The evacuated lamp was heated in a furnace for a number of hours to free it from gases, and a very high vacuum was maintained while the experiments were performed.

The results for the plates on which measurements have been completed are as follows:

Plate.	Mean Temp. T_m.	Watts W.	Θ °	ϕ °	Spec. Heat $S = \frac{c}{(\text{mass of filament}) \times 4.18}$
1	2485 K.	13.75	28.5 K.	(91.5)	.0450
2	2455	12.99	24.5	86.4	.0495
3	2435	12.49	24.5	87.1	.0477
4	2413	11.91	22.6	86.8	.0491
5	2368	11.03	21.2	86.1	.0485

Mean value of specific heat = .0479 $\frac{\text{calories}}{\text{gm. degree}}$.

[1] PHYSICAL REVIEW, VII., pp. 315–6, 1916.

Hence the atomic heat at constant pressure is 8.75 calories per gm. atom per degree. This agrees within the limits of experimental error with the results which Worthing[1] obtained by observing the way in which the resistance of a tungsten filament varied when the heating current was suddenly changed.

An attempt is being made in this laboratory to increase the accuracy of the oscillographic method, and to apply it to the determination of the specific heats of other metals.

An oscillograph might also be used to record the variation in temperature of a filament when a direct current is varied.

NORTHWESTERN UNIVERSITY,
November 7, 1921.

EFFECT OF TENSION ON THERMOELECTROMOTIVE FORCES BY MAGNETIZATION.

BY ALPHEUS W. SMITH.

THE application of tension to nickel at first lessens the change in resistance, length and thermoelectromotive force produced by a longitudinal magnetic field. For larger magnetic fields the reverse is true. In the case of nickel there is a proportionality between the change of length, resistance and thermoelectromotive force. In iron there is a parallelism between the effect of tension on the change of length and change of thermoelectromotive force. The greater the tension, the smaller the initial increase in the thermoelectromotive force and the smaller the magnetic field at which the reversal of the direction of the change takes place. At sufficiently large values of the magnetic field the initial increase in the thermoelectromotive force disappears and there is a decrease for all values of the magnetic field.

The variation of thermoelectromotive forces in iron-copper alloys is very similar to its variation in pure iron. The addition of copper to iron at first increases the fractional change of the thermoelectromotive force. When the alloy contains about 1.5 per cent. copper this fractional change is largest. Beyond this concentration there is a decrease. In these alloys there is a similarity between the Hall constant, the specific resistance and the fractional change of thermoelectromotive force. The first addition of nickel produces an increase in the fractional change of thermoelectromotive force. This is followed by a decrease and a later reversal both in the direction of the thermoelectromotive force and in the sign of its change.

Neither the gas-free theory of electric conduction and thermoelectromotive force nor the gap theory of Bridgman give satisfactory explanations of the effect of longitudinal magnetic fields on thermoelectromotive forces, length and resistance and their variation with tension. The assumption that the number of free electrons is determined by the frequency of the atom and that this number decreases with increasing frequency would lead naturally to the conclusion that an elongation would produce a decrease in frequency, an increase in the number of free electrons and a decrease in resistance. Where

[1] PHYS. REV., XII., p. 216, 1918.

the frequency of the atom and the number of free electrons are not the same functions of the magnetic field at different temperatures and tensions this form of explanation might give a reason for the variation of the thermoelectromotive force and for the influence of tension on it.

OHIO STATE UNIVERSITY.

POSITIVE RAY ANALYSIS OF LITHIUM AND ZINC.

BY A. J. DEMPSTER.

POSITIVELY charged atoms are formed by vaporizing the metal in an electrically heated capsule, and bombarding the vapor with electrons from a hot cathode. After falling through a definite potential the particles are deflected through 180° by a magnetic field, the semicircular path being smaller for the lighter than for the heavier. The different atoms are observed by means of their charge. Two components were observed in the case of lithium with atomic weights 6 and 7. The proportion of the two components was found to vary in different experiments. Preliminary experiments with zinc have given three strong components two units apart in atomic weight, and one weaker component one on the heavy side of the strong group and separated also by two units of atomic weight.

RYERSON LABORATORY,
UNIVERSITY OF CHICAGO.

A CONVENIENT CONTACTOR FOR SMALL CURRENTS.

BY FREDERICK J. SCHLINK.

ORDINARY drawing ink applied in the form of lines with a ruling pen will form an electrical path of sufficient conductivity to be used in connection with the oscillograph for recording the instants at which the lines pass by a brush or wiper. As it is frequently necessary to determine electrically the rate of translation or rotation of some moving part, the possibility of providing for the electrical contacts required by simply drawing lines on a strip of paper gummed to the moving part, affords great convenience, in comparison with the trouble and expense of constructing the usual composite commutator for the purpose. Moreover, the ink and paper contacting device will often be of negligible mass and inertia in relation to the part whose motion is under investigation. The lines may be connected to a common return circuit by drawing transversely across them a wide band of the same material, which in turn may be connected to a metallic return path through wire, metallic foil, or similar connection.

The contact pressures required will be extremely minute, and as the ink and paper are sensibly in the same plane, difficulty from bouncing of the brush will not be encountered unless the velocities are very high indeed. It is found that the drawing ink will carry a considerable amount of graphite in suspension; addition of this will increase the conductivity markedly, especially if the ink after drying be burnished and compacted to a glossy condition by the use of a smooth metallic tool.

It is found that in practice, if every fifth or tenth line is emphasized by being drawn somewhat wider than the others, the effect will be recorded in the oscillogram by the greater amplitude corresponding to the higher conductivity of the wider line. In exceptional cases, where, in order to obtain a high precision or "definition" of the contact, a very narrow line must be used, of correspondingly low conductivity, a d.c. amplifier introduced into the circuit will enable sufficient amplitudes to be obtained in the usual G.E. oscillograph.

There seems to be a fair possibility of obtaining a space-time curve direct by the use of a brush passing along, instead of transversely to such an ink line, in which case resistance would be cut in or out proportionally to the relative displacements of the brush and the line, but opportunity has not been available to try out this method. Undoubtedly a variable resistance of this character would not be constant in its value; this would not, however, be a matter of serious moment if the method were required only for occasional use, as a preparatory calibration could readily be made.

WESTERN ELECTRIC CO.,
NEW YORK,
May 27, 1921.

THE DIELECTRIC CONSTANT OF MICA.

BY J. R. WEEKS, JR.

IN looking for an average value of the dielectric constant of mica, the writer was impressed with the wide variations, 2.5 to 10, found by different investigators. It seemed likely that at least a part of this large variation might be due to air pockets or films between the various laminæ, especially since most of these low values were found on rather thick sheets. The high values, on the other hand, might be due to conducting films between the laminæ increasing the effective area of the electrodes.

Accordingly the dielectric constant of 12 different grades of mica was determined, using a shielded capacity and conductance bridge to measure the capacity of a condenser formed by two mercury electrodes and the sheet of mica. These 12 grades included some of those for which other investigators found abnormally high or low values.

It was found that:

1. When air films in the interior of the sample of mica were eliminated by splitting it along its natural lines of cleavage into thin sheets, in no case was the dielectric constant less than 6.4.

2. Where air films were plainly visible, the dielectric constant was low (2.9 to 4.8).

3. The most probable cause of very low values as found by some investigators is the existence of air films between the laminæ. These air films are in most cases very hard to see without carefully examining the edges of the sheets.

4. Stained sheets did not show a dielectric constant enough higher than the average value of 8.1 to determine the effect of stains in mica upon the dielectric constant.

5. No difference in the dielectric constant is readily discernible between the different grades or kinds of mica which were tested.

RESEARCH LABORATORIES OF THE
AMERICAN TELEPHONE AND TELEGRAPH COMPANY
AND WESTERN ELECTRIC COMPANY, INC.

A PHOTOMICROGRAPHIC STUDY OF A SERIES OF DRAWN TUNGSTEN WIRES.

BY L. P. SIEG.

THE writer has reported[1] on the effect of drawing on the coefficient of simple rigidity of ductile tungsten wires. These wires, five in number, were all drawn down from the same original wire, and so, presumably, had the same chemical constitution. Their rigidities were found to increase progressively with decrease in diameter. In the above published reports the hypothesis was advanced that if the drawing produced a surface effect, penetrating to a moderate distance, and if this surface state of the wire possessed the higher rigidity, then the results could be accounted for. It remained to examine the wires photomicrographcially to test the soundness of the theory.

Such a photomicrographical study with tungsten is difficult, because here one is not only confronted with preparing the samples for examination of their crystal structure, but this preparation must be good enough to enable one to see any differences in the structure. After many trials a satisfactory result was obtained. The wires were all mounted in a common soft copper frame, and held in position by forcing the copper, between the jaws of a vice, around the wires. In this position they were ground down, polished, and finally etched with boiling hydrogen dioxide. The photographs show a distinct demarcation in the larger samples between the surface layer, and the central portions of the cross sections. In the smaller sections, this surface layer occupies almost all the cross section, and in the smallest wire, the surface structure occupies the whole of the cross section. The radii of the wires varied from 0.00240 to 0.0227 cm.

While it was clearly possible to differentiate between the two crystal states, it was by no means, even with the highest magnifications, to be certain what this change really represented. The surface structure was such that details could scarcely be made out, whereas the outlines of the crystals in the central portions were relatively large, and clearly distinguishable. It is tentatively assumed that the crystals in the surface are extremely small, and separated by an unusually large amount of the so-called amorphous state. This amorphous state is probably groups of atoms, not sufficient in number to constitute genuine crystals. Most metallographers are of the opinion that the amorphous state is the one possessing the higher elasticity.

STATE UNIVERSITY OF IOWA,
October 29, 1921.

[1] PHYS. REV., 1, p. 70, 1913; Ia. Acad. Sci. Proc., 24, p. 207, 1917.

A SIMPLIFIED METHOD OF CORRECTING FOR THE DECREMENT OF A DECREMETER.

BY R. R. RAMSEY.

IN measurement of the decrement of an oscillating circuit the usual formula is

$$d + d_1 = \frac{\pi (C_r - C)}{C_r},$$

where d is the decrement of the circuit to be measured, aërial; d_1 is the decrement of the decremeter; C_r is the capacity in the decremeter circuit which makes the decremeter in resonance with the aërial; and C is the value of the capacity which reduces I^2, the mean value of the square of the current in the decremeter to $\frac{1}{2}I^2$. The method of correcting, usually given in all text books, is the method given by formula 63, page 94, in Radio Instruments and Measurements circular of the Bureau of Standards, No. 74. This formula is complicated and hard to manipulate. Since

$$d = \frac{R}{2L} T,$$

where R is resistance in circuit; L, inductance in circuit; and T, the period of oscillation, then

$$2d = \frac{R_1 + R}{2L} T,$$

when $R_1 = R$. R_1 can be determined by the "half deflection" method of measuring resistance.

Measure the decrement $D_1 = d + d_1$ in the usual method. Introduce resistance in the decremeter circuit until $R_1 = R$, and then measure the decrement again. In this case $D_2 = d + 2d$.

Then $d_1 = D_2 - D_1$.

In determining R_1 the half deflection method is used.[1] If the source is impulse excitation as in the primary of an oscillatory transformer containing a quenched gap, then $I^2R = \frac{1}{2}I^2(R + R_1)$. R_1 is the resistance inserted in the decremeter which reduces I^2 to one half its value.

If the source has small damping as in the secondary of an oscillating transformer or aërial circuit, then $E = IR = \frac{1}{2}I(R + R_1)$ where R_1 is the resistance which reduces the current in the decremeter to one half its value.

INDIANA UNIVERSITY,
BLOOMINGTON.

A NEW VISUAL NULL METHOD FOR CONDUCTIVITY DETERMINATIONS.

BY FABIAN M. KANNENSTINE AND ESME E. ROSAIRE.

THE balance point of an alternating current bridge is indicated by a direct-current galvanometer in an audion circuit. The method is independent of the

[1] Page 182 and page 188, B.S. Circular 74.

frequency impressed on the bridge, thus extending the usable frequencies above the present upper limit of 3,000 cycles per second. When an electrolytic cell was used as one arm of the bridge no difficulty was experienced in balancing with frequencies up to 15,000 cycles per second.

The frequency applied to the bridge is not limited by the characteristics of the human ear. The strain on the observer, incidental to all telephone methods, is eliminated. Readings could be repeated to one part in 50,000 with a galvanometer of only one megohm sensibility.

University of Chicago.

Phase Relations in Coupled Circuits.

By N. H. Williams.

The complete solution of coupled circuits has been given in several different forms by different authors.

The operation of coupled circuits by means of the three electrode vacuum tube for producing sustained oscillations introduces some conditions that are slightly different from those giving rise either to free oscillations or to oscillations forced by an e.m.f. in one of the circuits.

This paper presents a method of measuring the difference in phase between the currents in different parts of a high-frequency system and in particular deals with the difference between the phase relations with positive coupling and those occurring when the coupling is negative.

University of Michigan.

The Change of Mobility of the Positive Ions with Age in Oxygen and Nitrogen.

By Henry A. Erikson.

From results published earlier[1] it is evident that the positive ion, as produced in air at normal pressure by the α particles from polonium, increases in size during the first fraction of a second of its life. The mobilities of the positive and negative ions are nearly the same when measured within an interval of the order of 0.01 second after formation. The normal ratio of 1.37 between the negative and positive mobilities is obtained only after an interval of the order of .01 second. The mobility of the negative ions, when measured at the end of the intervals mentioned above, is found unchanged.

In order to ascertain if the above results are peculiar to air the following investigation of oxygen and nitrogen separately was undertaken. The method used was the same as in the earlier investigations. The ions were carried by means of a current of air between two plates which were at a difference of potential. The ionic current at different down stream distances on one of the plates was measured. By plotting these ionic currents against the corre-

[1] Phys. Rev., XVII., p. 400. Phys. Rev., XVIII., p. 100.

sponding down stream distances a curve is obtained from which it is possible to determine in part the nature of the carriers. The apparatus was enclosed in a vessel which could be filled with the gas under investigation.

The experiments show that both in oxygen and in nitrogen the negative ion does not change. The positive ion, however, does in each case undergo a change. It is also noted that the change in the mobility of the positive ion in oxygen is somewhat more rapid than in nitrogen.

As a working hypothesis the writer assumes that in the process of ionization, an electron is removed from one of the atoms in the molecule. This electron quickly attaches itself to a neutral molecule and this constitutes the negative ion. The positive remainder of the molecule constitutes the initial positive ion. As both of these ions have the same size and charge they move with equal velocities under the action of an electric field. The initial positive ion sooner or later, in a diatomic gas, attaches itself to another atom forming an ion of mass three.

If the velocity of an ion, in any one gas, is inversely proportional to its mass, the ratio of the mobilities of the negative and positive ions should be unity soon after formation. The mobility of the positive ion will then gradually diminish to two thirds the initial value and the ratio of the mobilities becomes 1.33 which is about the final ratio observed in the case of air, nitrogen and oxygen. Postulating N_3 in the case of nitrogen may not however be permissible. In the case of CO_2 the positive ion does not attach itself and the mobility ratio remains unity.

In order to test the above hypothesis the writer is proceeding to investigate as many gases as possible. It is hoped that a sufficient supply of helium may be obtained. This monatomic gas should give evidence as to the validity of the above hypothesis.

UNIVERSITY OF MINNESOTA,
September 5, 1921.

SPHERICAL ABERRATION IN THIN LENSES.

BY T. TOWNSEND SMITH.

IT is well known that the spherical aberration of a thin lens can be expressed in terms of the position of the object, the radii of curvature of the lens, and the index of refraction of the glass, and that the algebraic formula so obtained may be used in the calculation of lens systems in which the aperture is not too large. Somewhat recently Mr. T. Smith[1] of the National Physical Laboratory has called attention to the fact that such calculations have practical value and that in certain cases it is unnecessary to check them by trigonometric computation.

By choosing as the determining factors the focal length of the lens, a shape factor (s), and a position factor (p), (credited to Coddington) it is possible to express the aberration in the form given herewith, where A, B, C, and D are

[1] London Physical Soc., Proc., 30: 119, 1917–18.

constants which involve only the index of refraction:

$$\Delta\left(\frac{1}{v}\right) = \frac{h^2}{f^3}(As^2 + Bsp + Cp^2 + D).$$

The quadratic in this expression is a function which determines the effect of the shape of the lens and of the position of the object upon the longitudinal aberration. By taking proper account of the focal length of the lenses, this function may be used to calculate the spherical aberration of any system of lenses in contact. In particular it may be used to determine the conditions under which the spherical aberration may be eliminated. The calculations may be made analytically or graphically. The graphical work can be simply done and the results are in some cases accurate enough to be used as a guide in the choosing of a suitable combination.

The conditions under which a pair of lenses in contact may be corrected for spherical aberration have been worked out graphically, and curves showing the possible combinations for a distant object have been obtained for a few of the commoner types of optical glass. The condition that the lens pair may be cemented and Taylor's[1] condition for the elimination of coma have been indicated on the diagram. The effect of slight changes in the shapes of the lenses has also been calculated for a lens pair made from the "ordinary crown" and the "dense flint" glasses.

Brace Laboratory, University of Nebraska.

A Low Resistance Connection with a Revolving Shaft.

By A. P. Carman.

The problem was to make an electrical connection with a coil on a revolving shaft, the resistance of the connection to be small and constant. The following device has proved to be practical. In Fig. 1, B is one end of the shaft; a small hole is bored along the axis of the shaft, and the end of the coil is brought to an insulated copper plug P; the rubber or amber bushing RR gives good insulation from the shaft. Extending in the line of the shaft is the wire WW of about 30 cm. length; in most cases No. 25 B. & S. gauge wire was used though No. 20 and No. 30 wires were used with equal success. The wire WW runs through TT a trough of mercury of about 20 cm. length, passing the wire through

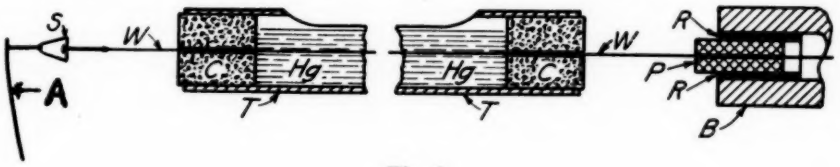

Fig. 1.

ample holes in the corks CC. The wire terminates in a small swivel S, and this swivel is attached to a spring A by which the wire is kept stretched and

[1] H. Dennis Taylor, System of Applied Optics, p. 195, equation (4).

straight. The round pin head turns freely in the hole of the fixed part of the swivel when the shaft rotates. Outside electrical connection is made with the wire by means of the mercury. This device is used on both ends of the shaft so as to complete the circuit. In the first trials, the shaft formed part of the circuit, but there were disturbing thermal and contact electromotive forces at high speed. By completing the circuit with a wire through a hole along the axis of the shaft, these disturbing electromotive forces were eliminated. The following are examples of changes of resistance at rest and at a speed of about 4,000 r.p.m.

R. at rest.....	.124843	.124391	.123488	.0733497	.072447	.065044
R. at 4000 ± r.p.m.....	.132296	.131167	.131167	.972447	.072898	.060948
Differences.....	.00745	.006776	.007679	.000902	.000451	.000904

These resistances were determined with a Carey-Foster bridge. The different resistances at rest were due to use of different connecting wires *WW*. It is seen that the changes of resistance between rest and motion varied between .5 and .9 of one per cent. of the actual contact resistance at rest, and of course a much smaller percentage of the total resistance of the circuit. Potentiometer measurements showed that the disturbing thermal and contact electromotive forces were very small, of the order not more than one hundred thousandth of a volt. The above contact is being used in an investigation in progress. The device is reported now as it may be important for others in their investigations.

THE EFFECT OF PRESSURE AND GAS CONTENT ON THE ACTION OF VACUUM-TUBE DETECTORS.

BY H. A. BROWN AND CHAS. T. KNIPP.

IN recent years there has been put on the market a class of vacuum tubes known as "gas content detector tubes." The advantage of using this type of tube as a detector lies in the fact that it does not require a high-plate voltage for its operation. It is commonly believed that such a tube gives louder response to signals than one having a higher vacuum. It is well known that the low vacuum tubes have critical adjustments of plate voltage and filament current to secure the best response to signal currents. This is not the case for high vacuum tubes. The purpose of the present investigation was to show from experimental data just how the degree of vacuum and the nature of the gas in the tube affect its operation as a detector.

The pressure of the gas in the tube was varied and readings were taken of the plate voltage for the loudest signal response (called the "operating voltage"), and also of the comparative intensity of signal response for various measured pressures. This was done for several tubes of the same type and for tubes of different types and makes. Measurements of the operating voltage

versus pressure were also made with different gases successively introduced into the same tube.

The effect of various pressures and kinds of gas upon the critical adjustment characteristics was also measured. The intensity of response passes through a maximum for each pressure as plate voltage or filament current increases. Different gases were successively introduced into the same tube and measurements were made of comparative best signal response for each gas. The results were arrived at after repeating the test for several tubes, and are summarized at the end of this abstract. Measurements were made of the amplification constant and mutual conductance of different tubes with varying plate voltages for different pressures. If the amplification constant is a function of the geometry of the tube, the presence of gas alters the *effective* geometry of the tube as the curves clearly show. When gas is present the amplification constant decreased with increasing filament current above normal values while the measured value of mutual conductance increased. However, the intensity of signal response passed through a maximum for increasing filament current. The variations of the mutual conductance were very similar to the variations of intensity of signal response with varying plate voltage at different pressures. Data were taken which showed that the characteristic humps in the plate current-grid voltage curves for tubes containing gas were not present when the tube content was helium, the filament being tungsten, nor were humps present for oxide-coated filament tubes containing neon or air.

The tabulated conclusions from the results obtained follow:

1. The degree of vacuum in a detector tube is important. A pressure of .0025 to .005 mm. of mercury gives two to three times as loud response as does a pressure of .05 mm. of mercury.

2. The operating voltage for the most desirable vacua above mentioned is 40 to 50 volts.

3. The adjustments of operating voltage and best filament current are much easier at the above degrees of vacua, and this fact, with the doubled intensity of audible response, fully justifies the provision of a higher plate voltage than is now needed for many low vacuum detector tubes.

4. The operating voltage varies with the pressure in the tube along a curve of the form $E_0 = e_i(a)^{1/P}$. E_0 is the operating voltage, e_i is probably the ionizing potential of the gas, P is the pressure, and "a" is constant. For various gases the variation gives very similar curves.

5. The bend in the above curve occurs at the point of best audibility of response, or .003 to .005 mm. of mercury, and operating voltages of about 40 to 50 volts. To the right of the bend (increasing pressure) adjustments of operating voltage and filament current become critical.

6. The introduction of neon, nitrogen, or carbon dioxide does not show any change in audibility or intensity of response from that obtained with air in the tube. Argon gives a somewhat louder response, and helium a slightly weaker response.

7. Hydrogen gives a very much weaker audibility of response.

8. The degree of critical adjustment of plate voltage and filament current for best response is about the same for air, nitrogen, neon, and carbon dioxide. Hydrogen tubes are somewhat more critical.

9. The operating voltage is approximately 30 per cent. higher for helium-filled tubes than for those mentioned above at the same degree of vacuum.

10. The operating voltage is considerably less critical for helium-filled tubes than for any other gas content, and compares with those tubes having fair vacuum.

11. Mercury vapor gives better signal response than the other gases tried, while for the former the operating voltage is lower at similar pressures. The operating voltage for mercury vapor varies from 16 to 22 volts depending on the vapor pressure and hence on the temperature of the walls of the tube. The operating voltage and best filament current are also less critical for mercury vapor than for neon, argon, air, or carbon dioxide.

12. For all of the gases tried the audibility of signal response rises to a maximum as the pressure is lowered below .005 mm. of mercury.

13. The operating voltage at low vacuum depends on the ionization potential of the gas in the tube, but the former is about five or six volts higher than the latter up to pressures of .06 to .08 mm. of mercury. Comparative operating voltages for helium, argon, neon, and mercury vapor tube content show this to be true.

Several other interesting results, and a full discussion of the various factors entering and precautions observed, are described in the extended paper which will be published soon.

UNIVERSITY OF ILLINOIS,
August, 1921.

SOME REMARKS ON ELECTROMAGNETIC INDUCTION.

BY S. J. BARNETT.

THIS paper is devoted to historical, critical, and expository comments on matters connected with experiments previously made by the author in various parts of the field of electromagnetic induction.

Experiments *on the motion of insulators in magnetic fields* by Faraday, Blandlot, H. A. Wilson, M. Wilson, and the author are referred to, and the theory is given in sufficient detail to show that the interpretation given by Larmor and Wilson is not tenable. Theoretical difficulties involved in Hertz's theory are pointed out. An additional observation made by the author is described.

Attention is called to the facts that the author's experiments *on electromagnetic induction in the case of rotary motion*, often misquoted, were *not* made to solve the so-called problem of unipolar induction, and that the results obtained were clearly stated in the original paper to be in accord with current

electrical theory, viz., that of Maxwell and Lorentz. The complete clearing up of the problem of unipolar induction on the theoretical side is attributed to Larmor and Pegram. Reference is made to a recent paper on the subject by Swann, which gives the theory in detail, but contains little new material. The author's interpretation of his own experiments is given; and his earlier demonstration that they could not be used to settle the problem of unipolar induction is referred to, with critical comments.

The author's experiments *on electromagnetic induction and translatory motion* are briefly described and his earlier and later interpretations are referred to. The latter is identical with the interpretation published much later by Swann. The theory for both a strictly two-dimensional field and the actual case of the experiments is given according to Maxwell's theory by the method of the vector potential.

The results of the experiments on rotary and translatory motion are contrasted.

CARNEGIE INSTITUTION.

THE EXISTENCE OF SMALL IONS OF VERY HIGH MOBILITIES.

BY OSWALD BLACKWOOD.

SMALL ions of very high mobility have been found by Nolan[1] in the ionization from water spray and from radioactive bodies. He finds values more than *seven times* larger than that commonly accepted.

The results for spray ions are interesting since this field has been little explored. The ionization from radioactive bodies, however, has been investigated by many workers using methods much more precise than Nolan's. To the writer's knowledge no one has ever found such large values for ions in undried air. Since they have used methods which are much more accurate than Nolan's, the reality of his ions cannot be admitted even tentatively until their existence has been verified by other methods.

The writer presents evidence indicating that the results are, in fact, capable of another interpretation.

The apparatus consists of a plate condenser 25 cm. long and 10 cm. high, the upper plate being connected to an electrometer, while the potential of the lower one may be given any desired value. The radium emanation is contained in a leaden trough near one end of the charged plate. One centimeter above this trough is a lead shield which is supposed to limit the production of ions to the small volume immediately below it. A steady air current passes through the condenser carrying the ions forward while the electric field drives them vertically. At a critical voltage the beam of ions arrives at the electrometer plate and the current achieves its maximum value.

Nolan finds that the ions are driven to the plate when the voltage is far

[1] Proc. Royal Irish Acad., Vol. XXXIII. (*A*) (1916); Proc. Royal Society (*A*), Vol. XCIV., p. 112 (1918); Proc. Royal Irish Acad., Vol. XXXV. (*A*), p. 38 (1920).

below its critical value. He assumes that this indicates the presence of high velocity ions. The writer, however, shows conclusively that it is due to the fact that ions are produced not only in the constricted space below the shield, but also throughout the entire volume of the condenser. A wire screen electrically connected to the lower plate was placed one centimeter above it so that no ions produced under the lead shield should reach the electrometer plate. This screening reduced the electrometer current to only 75 per cent. of its former value, which showed beyond doubt that most of the ionization is produced in the upper part of the condenser. The difference between the two readings gives the electrometer current due to the ions formed near the lower plate. This corrected curve cuts the axis at the theoretical critical voltage and gives the commonly accepted mobility value for the small ion.

THE UNIVERSITY OF PITTSBURGH.

EFFECT OF LUNAR GRAVITY UPON A QUARTZ THREAD BALANCE.

BY R. C. HARTSOUGH.

The Construction and Description of the Apparatus.—The construction of the balance is somewhat after Threlfall's "gravity balance." The chief addition is a long vertical lever arm and suspended mirror for magnifying small movements. This is due to Lord Kelvin in his "Lunar Disturbance of Gravity" experiments.

The shape of the apparatus is of a large T, the horizontal part is 60 cm. long and the vertical part is 50 cm. long. Instead of silvering, plating and soldering the mounting of the quartz thread, type metal was found entirely satisfactory and much surer and quicker of application.

These specifications of the apparatus will give a correct idea of the balance as used.

Size of quartz thread	0.04 mm. diameter
Length of quartz thread	55.7 cm.
Length of short weight-lever	2.0 cm.
Length of long observing-lever	26.5 cm.
Weight on weight-lever	0.10 gm.

Five complete twists were given each end of the quartz thread in order to hold the weight-lever horizontal and the observing-lever perpendicular.

The apparatus was enclosed in a T-shaped tube of brass and was evacuated to 0.03 mm. mercury pressure, and dried with phosphorous petoxide. The apparatus was placed in the basement on a solid base, however, passing trucks gave a very noticeable vibration. The temperature of this room was constant to within one degree in 24 hours. A galvanometer telescope-scale was used for observing deflections. Distance was 60 cm. The following readings and curve are typical of many taken.

Date.	Time.	Scale	Room Temp.	Remarks.
Nov. 7.....	7:30 A.M.	23.3	19.0° C.	
	8:45 A.M.	26.7	18.5	
	12:00 Noon	22.0	19.0	
	2:30 P.M.	19.2	19.2	
	5:30 P.M.	17.4	19.4	
	6:00 P.M.	16.6	19.5	Moon at zenith 6:12
	6:14 P.M.	15.9	19.5	
	6:20 P.M.	15.8	19.3	
	8:00 P.M.	16.1	19.8	
	9:15 P.M.	16.5	19.8	
Nov. 8.....	6:30 A.M.	22.7	19.3	
	8:00 A.M.	23.5	19.2	

The evidence of this experiment shows that if the earth's gravitational force is balanced against the torque in a quartz fiber, the moon will disturb that balance gradually over 24-hour periods. A maximum decrease of the earth's gravitation occurring with the moon at its upper culmination and a minimum at the moon's lower culmination.

The author expects in the near future to try to detect any lag effect in the gravitation of the moon and the sun.

The facilities of the Laboratory of Physics of the University of Illinois through the courtesy of Professor A. P. Carman were placed at my disposal for this investigation, while the council and help of Dr. C. T. Knipp were a large factor in its success.

LABORATORY OF PHYSICS,
UNIVERSITY OF ILLINOIS,
September, 1921.

ON THE ELECTRICAL PROPERTIES OF ILLIUM.

BY CHAS. T. KNIPP AND J. L. HALL.

ILLIUM was first produced in wire form early during the summer of 1921, making possible the measurement of a number of the electrical properties of this remarkable chemically resistant alloy. The wire for these experiments was generously furnished by Professor S. W. Parr, of the Department of Chemistry, University of Illinois. It was of the particular type known as "Illium-B."

The temperature coefficient of illium was found to be .000479 ohm per degree Centigrade. In this determination a wire of length 147.1 cm. and mean diameter .96 mm. (corresponding to No. 16 B. & S. gauge) was used. The range of temperature was from 0 to 70° C. and the value given above is the mean of 13 observations over 10° intervals.

The resistivity, using the same sample on the basis of the resistances measured over the above range of temperature, was found to be, when extrapolated to zero degrees C., 91.61×10^{-6} ohms.

The largest thermoelectromotive force is produced when illium is coupled with constantin. It produces a smaller thermoelectromotive force when coupled with nickel, and smaller still with german silver; while with platinum, copper and chromel there is but little thermoelectromotive force generated, and with manganin none at all.

The illium-constantin couple over the range 0 to 400° C. was found to be almost identical in its behavior with that of copper-constantin.

UNIVERSITY OF ILLINOIS,
August, 1921.